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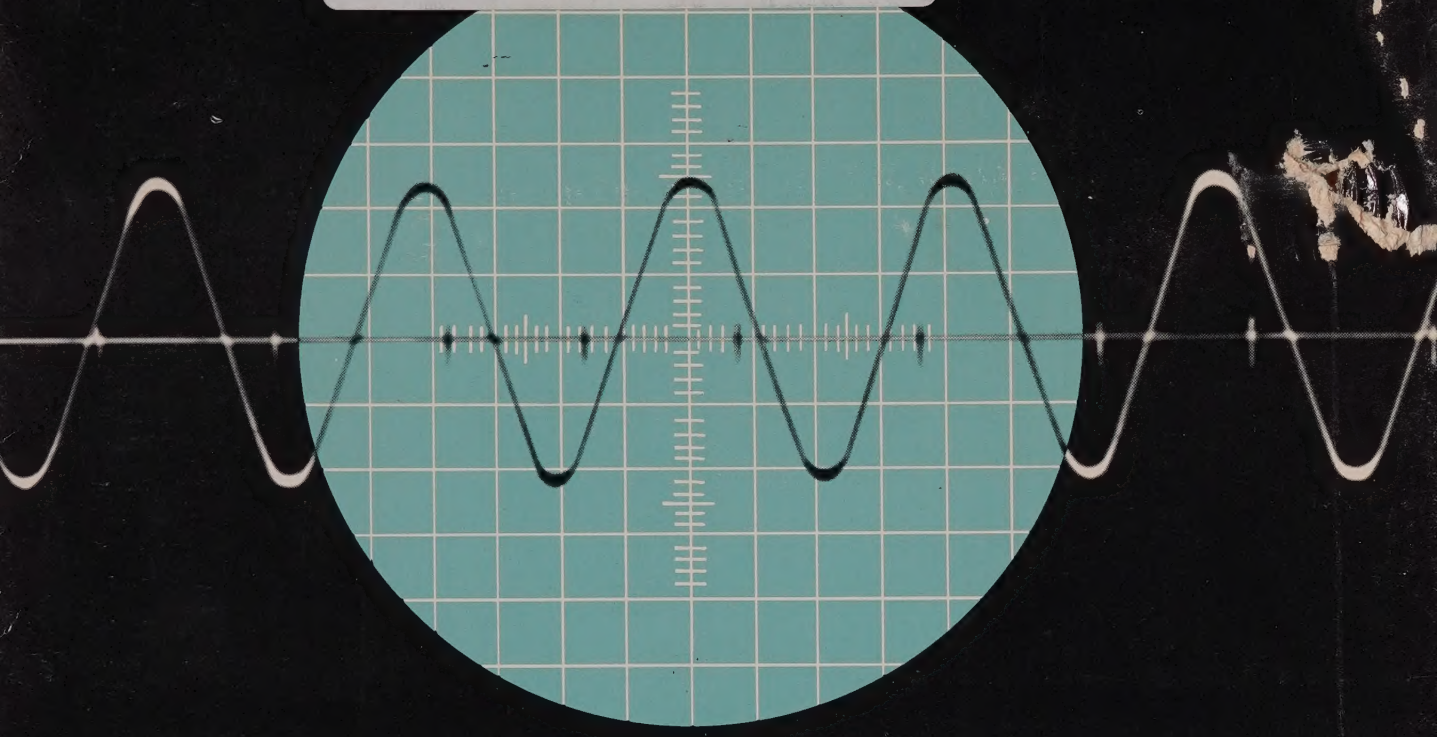
Technical Manual



3-WAY
COMPARATOR
MODEL TC-3

JERROLD
ELECTRONICS CORPORATION
INDUSTRIAL PRODUCTS DIVISION
PHILADELPHIA 32, PENNA.

JERROLD®

INSTRUCTION MANUAL
435-464

SOLID-STATE

3-WAY COAXIAL COMPARATOR

MODEL TC-3

JERROLD ELECTRONICS CORPORATION
LKE, March 1965

INDUSTRIAL PRODUCTS DIVISION
PHILADELPHIA, PA. 19132

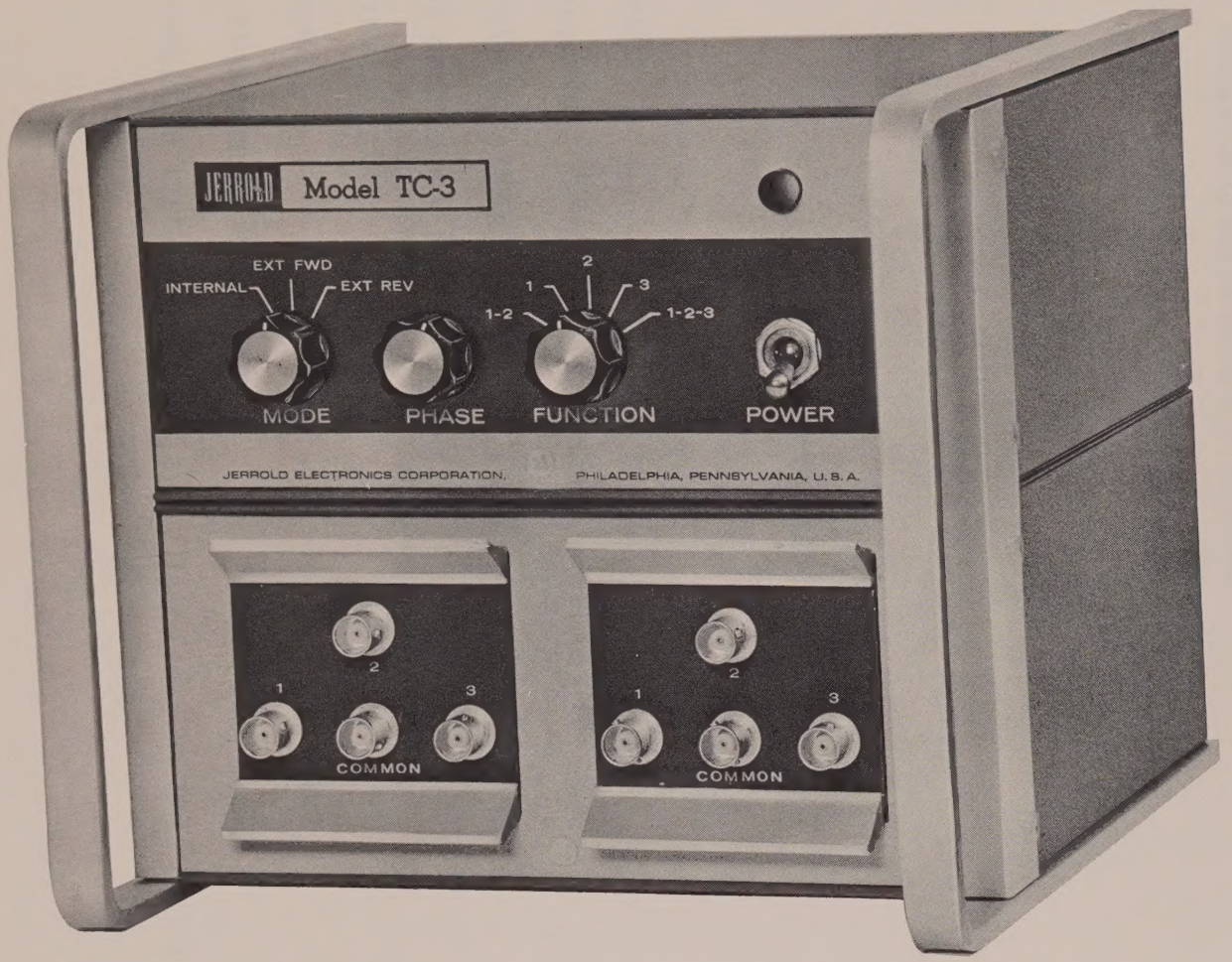


Fig. 1 PORTABLE 3-WAY COAXIAL COMPARATOR
MODEL TC-3

NOTES: 1. This manual is shipped with Model TC-3, Serial #

2. The data in this manual incorporate all Engineering Changes up to and including E. C. O. # 3425.

3. All data in this manual are subject to change without notice.

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3-WAY COAXIAL COMPARATOR MODEL TC-3

DESCRIPTION

Model TC-3 is a high-speed, electronically controlled switching unit for the simultaneous display of two or three waveforms on an oscilloscope.

In addition, the circuitry permits manual switching for individually displaying any one of three waveforms.

In appropriate test set-ups, together with such instruments as a sweep generator, variable attenuators, and other accessories, Model TC-3 will permit fast, repetitive laboratory or production line "measurements by comparison". R-F transmission parameters such as gain, loss, frequency response, and reflection coefficient (return loss, VSWR) of a test circuit can be compared against one or two preset references (e. g. high and low limits). The frequency range of Model TC-3 extends up to 1200 MC, important for "measurements by comparison" in the UHF range.

Model TC-3 consists of two basic units: one housing the solid-state driver circuitry and controls, the other housing the two coaxial switch assemblies. Each switch assembly has three dry reed relays mounted to form a single-pole, triple-throw coaxial switch. In standard models the two basic units are mounted one on top of the other to form an instrument which is portable and convenient for bench-use.

For 19" relay rack mounting, special brackets (Model TC-3-RK) can be ordered for installing the two units side by side, requiring only 3 1/2" vertical rack space.

The power input circuit of Model TC-3 is designed to permit operation from 115 or 230 vac, 50 or 60 cps, simply by changing links on an internal terminal board and by changing the fuse.

SPECIFICATIONS

FREQUENCY RANGE	dc to 1200 mc
IMPEDANCE, all terminals	50 ohms
VSWR, all terminals	
dc - 1000 mc	1.10:1 max. (26 db min. return loss)
1000 - 1200 mc	1.22:1 max. (20 db min. return loss)
ISOLATION, each switch	30 db min. at 1000 mc
INSERTION LOSS, each switch	less than 0.2 db at 1000 mc
SWITCHING TIME (energize, transfer and bounce time)	less than 1.0 millisec.
MAX. DC POWER RATING FOR SWITCH CONTACTS	1 watt, 100 ma, 250 vdc
CONNECTOR TYPE	BNC
POWER INPUT	115 vac, 50/60 cps, 100 ma 230 vac, 50/60 cps, 50 ma
POWER DRAIN	11.5 watts
FUSING	115 vac: 1.0 amp. 230 vac: 0.5 amp.

OPERATION

GENERAL

1. This section explains the function of the controls and how to connect the instrument in a typical equipment set-up. Because Model TC-3 can be applied in many different test arrangements, and because the sequence in which connections are made and controls adjusted has no bearing on the proper functioning of the instrument, no detailed operating procedure is given. Instead, Jerrold Technical Newsletter Vol. 2 is appended, illustrating various applications of Model TC-3. Also, in describing the operation of the instrument, frequent reference will be made to Fig. 10 which shows the TC-3 connected to display simultaneously on an oscilloscope the maximum response and the 3-db down-point of a resonant circuit.

2. The switching frequency encountered in Model TC-3, when it is operated with internal sync, depends upon the power line frequency. Wherever this dependence is relevant, the condition that exists when the TC-3 is powered from a 60 cps source will be given first, and the condition that exists when the TC-3 is operated from a 50 cps source will immediately follow in parenthesis; e. g., 60 cps (50 cps).

3. After unpacking the instrument, first inspect it for any damage that may have been caused in transit. See that the fuse is in place and that the switch head cables are properly mated to J1 and J2 on the rear apron.

4. The sweep generator used with Model TC-3 must provide symmetrical sweep. Return trace must be unblanked for three-way switching and for two-way switching with external sync; for all other modes, the return trace may be blanked.

5. CAUTION: The maximum d-c input as specified for the dry reed relay contacts in the switch heads must not be exceeded!

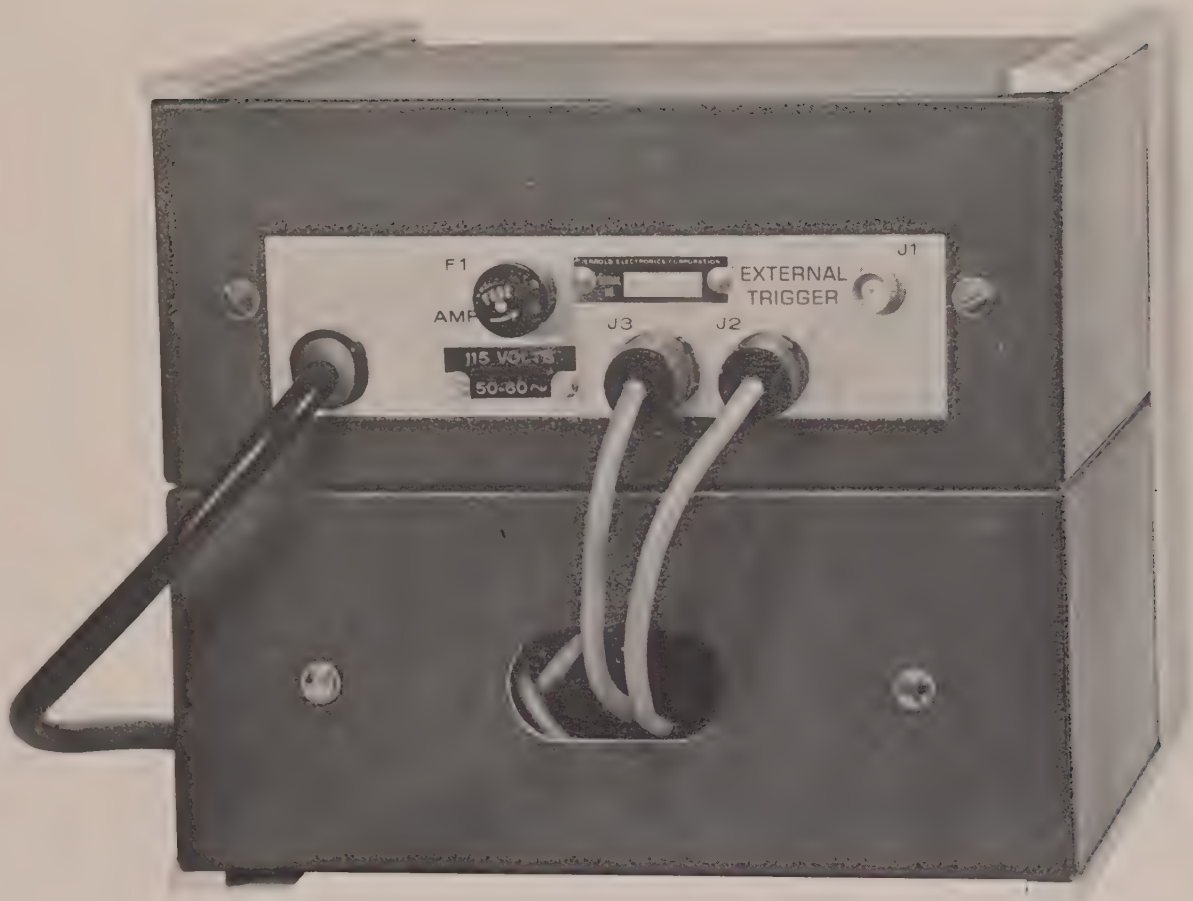


Fig. 2 PORTABLE 3-WAY COAXIAL COMPARATOR
MODEL TC-3
REAR VIEW

CHART OF CONTROLS

NAME	POSITION	TYPE AND CIRCUIT REFERENCE	FUNCTION
		FRONT PANEL	
MODE	INTERNAL	Rotary Switch S2	Operating from internal synchronizing input
	EXT FWD		Operating from external synchronizing input (with scope trace traveling forward)
	EXT REV		Operating from external synchronizing input (with scope trace traveling in reverse)
PHASE	Clockwise	Potentiometer R2	Phasing adjustment of scope patterns
	Counter-cw		when operating in INTERNAL mode
FUNCTION	1-2	Rotary Switch S3	Automatic switching for simultaneous display of two wave forms.
	1 2 3		Manual switching for display of any one of three wave forms.
	1-2-3		Automatic switching for simultaneous display of three wave forms.
POWER	Up	Toggle Switch S1	Energizes unit and pilot light.
	Down		De-energizes unit and pilot light.
1 2 3 COMMON		BNC Fittings 50 ohms J101 J102 J103 J104	Switch head connectors. There is one set of these connectors for each head.
		REAR PANEL	
EXTERNAL TRIGGER		BNC Fitting J1	Connects external sync signal to TC-3
J2 and J3		7-pin plugs J2 and J3	Interconnect driver and switch units.
1 AMP		Fuse F1	Fuses power supply. (change to 0.5 amp for 230 vac operation)

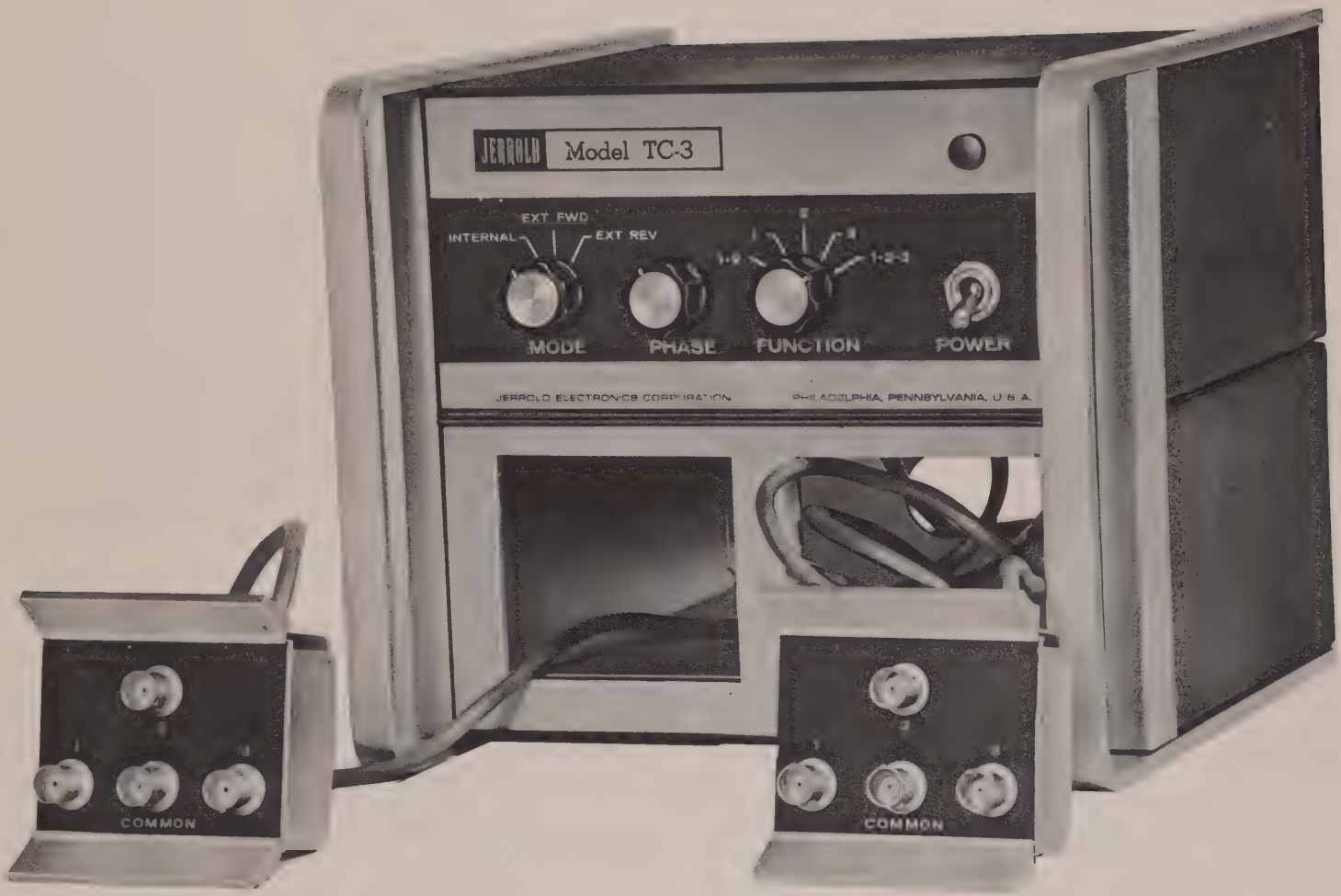


Fig. 3 PORTABLE 3-WAY COAXIAL COMPARATOR
MODEL TC-3, SWITCH HEADS REMOVED

THE SWITCH HEADS

1. Connections to the two switch heads are made through the four fittings marked 1, 2, 3 and COMMON on the front face of each head. When connecting the TC-3 into a test set-up,select one head to serve as the input head, the other to serve as the output head. As the two heads are identical and interchangeable, either head may be selected to serve as input or output unit.

2. For a typical 3-way switching operation, set up the equipment as diagrammed in Fig. 10. Connect the output of the sweep generator to the COMMON fitting on the input head; connect the COMMON fitting on the output head to the input terminal on the detector. The detector may be a plug-in unit on the sweep generator, or it may be an external detector. Connect the output of the detector to the vertical input of the oscilloscope.

3. The reference devices and the circuit under test may now be connected. Connect the input of the first reference device to fitting 1 on the input head; connect the output of the first reference device to fitting 1 of the output head.

   Connect the input of the second reference device to fitting 2 of the input head, the output of the second reference device to fitting 2 of the output head.

   Finally, connect the input of the circuit under test to fitting 3 on the input head, the output of the circuit under test to fitting 3 on the output head.

NOTE: For 2-way switching with only one reference waveform required, the circuit under test is connected in place of the second reference device.

4. Each switch head can be removed from the housing by first squeezing together its spring-loaded protrusions at the top and bottom and then extracting the head. This feature permits placing the heads close to the device under test in applications where jumper cable lengths may be critical; e. g., when measurements in the gigacycle range are to be made. Fig. 3 shows the TC-3 with switch heads removed from the housing. The cable lengths provided permit placing the heads as far as three feet from the housing. Where greater distance is required, any lengths of cable may be added.

THE FUNCTION SWITCH

1. The FUNCTION switch has two positions for automatic switching: 1-2 for switching between two devices, and 1-2-3 for switching between three devices. The switch also permits manual switching among three devices (positions 1 and 2 and 3) for displaying individual waveforms.

2. Switch positon 1-2: Refer to Fig. 10, removing reference B and replacing it with the circuit under test. Once power is applied to the TC-3, it begins to operate; first, switches S101 will close, feeding the sweep signal through reference A to the detector and thence to the oscilloscope. The switches remain closed for a time interval determined by the switching rate; then the switches open. At this instant switches S102 close, feeding the sweep signal through the circuit under test to the detector and to the oscilloscope. Switches S102 remain closed for the same period as switches S101. Then switches S102 open, switches S101 close and the cycle is repeated.

3. Switch positions 1 and 2 and 3: These switch positons permit displaying individual waveforms. With the FUNCTION switch set to position 1, only switches S101 close, and they remain closed until the FUNCTION switch is rotated to position 2 and 3, where the same function is performed by switches S102 and S103, respectively.

   No direct switch-over from position 1 to position 3 is possible. The same holds for switch-over from positon 1-2 to position 1-2-3.

THE MODE SWITCH

1. The MODE switch selects a 60 cps (50 cps) signal from the power supply, or an externally generated signal, to synchronize the TC-3 with the sweep generator.

2. Switch position INTERNAL: This switch position is selected when the sweep rate is symmetrical and locked to the 60 cps (50 cps) line. Switching occurs at the rate of 30/sec. (25/sec.), i.e., each switch is opened and closed 30 (25) times each second.

3. Switch positions EXT. FWD. and EXT. REV.: These positions are selected when the sweep rate is non-symmetrical or less than 60/sec. (50/sec.). In these instances, the blanking pulse of the sweep generator is applied to the EXTERNAL TRIGGER fitting J1 at the rear apron of the TC-3 for synchronization. The pulse amplitude is not critical; however, in order for the TC-3 to trigger, the pulse must go through zero. If the blanking pulse does not do this, it must be applied to the TC-3 trigger input via a high-value capacitor.

   Since the switching rate for two-way switching with external sync is the same as the sync rate, the display time allowed in this mode is suitable for low sweep rates when a short persistence oscilloscope is employed in the test set-up; however, no zero trace line is produced in this mode. This trace may be obtained, at the sacrifice of display time, simply by operating the TC-3 with the FUNCTION switch set to 1-2-3 and leaving one of the switch head inputs unused.

   In three-way automatic switching, the choice between the EXT FWD and EXT REV positions is irrelevant to the operation of Model TC-3. However, in two-way switching, this choice determines the starting point of the oscilloscope trace. In one

position the trace of the circuit under test begins at the left and progresses to the right; in the other position, the trace begins at the right and progresses to the left. This effect is noticeable only at very slow sweep rates. It should be noted that the designations FWD and REV are for reference purposes only. The proper switch positions for the two sweep modes have to be determined individually for each TC-3 unit at the time it is used with an external trigger signal.

THE PHASE CONTROL

The front panel mounted PHASE control is used when operating in INTERNAL mode. It permits adjustment of the phase of the 60 cps (50 cps) signal so that switching will be in phase with the sweep signal.

CIRCUIT DESCRIPTION

GENERAL

Model TC-3 comprises a built-in power supply driving pulse generating and amplifying circuits which operate six dry reed relays. The relays form two single-pole, triple-throw switches, one switch in each head. The circuit stages and signal flow are block-diagrammed in Fig. 4. Dwg. 861-601 gives the schematic circuit.

POWER SUPPLY AND PHASE SHIFTER

The power supply is a full-wave rectifier circuit employing line transformer T1, silicon rectifiers CR1, CR2, and filter capacitor C2. The secondary of T1 produces 13.5 vac, is tapped at the center and fused by F1 to ground. When the primary connections of T1 are changed from 115 to 230-volt operation, the factory-supplied 1.0a fuse should be replaced with a 0.5a fuse.

The phase shifter circuit comprises C1, L1 and PHASE control R2 connected across the secondary of transformer T1.

The dc output of this circuit stage is -7.5 volts, required to drive the other circuit stages.

SCHMITT TRIGGER AND FLIP-FLOP

Depending on the position of MODE switch S2, either the 60 cps (50 cps) signal from the phase shifter or an externally generated signal is applied to the input of Q5/Q6 connected in a Schmitt trigger circuit. This circuit provides an output of constant peak value for the period that the input waveform exceeds a specific voltage. The clipped output of this circuit is a square wave which has the same frequency as the synchronizing source. Where an external synchronization signal is used, it must be a square wave pulse which passes through zero. The pulse train at the output of the Schmitt trigger is differentiated by C6 and R16 to trigger the flip-flop Q3/Q4.

The signal at the collector of Q4 is applied to diode CR5 as one input to AND gate CR5/CR6. The signal at the collector of Q4 is coupled to diodes CR9 and CR10 and AND gates CR8/CR9 and CR7/CR10, respectively. The signal at Q3 also is differentiated by C5 and R10 and fed to diodes CR3/CR4 in the counter circuit.

THE COUNTER CIRCUIT

The positive-going spikes of the differentiated pulses appearing at CR3 and CR4 trigger the counter Q1/Q2 at half the rate of the flip-flop, producing pulse trains at the collectors of both transistors. In this condition the circuit acts as a 2:1 counter.

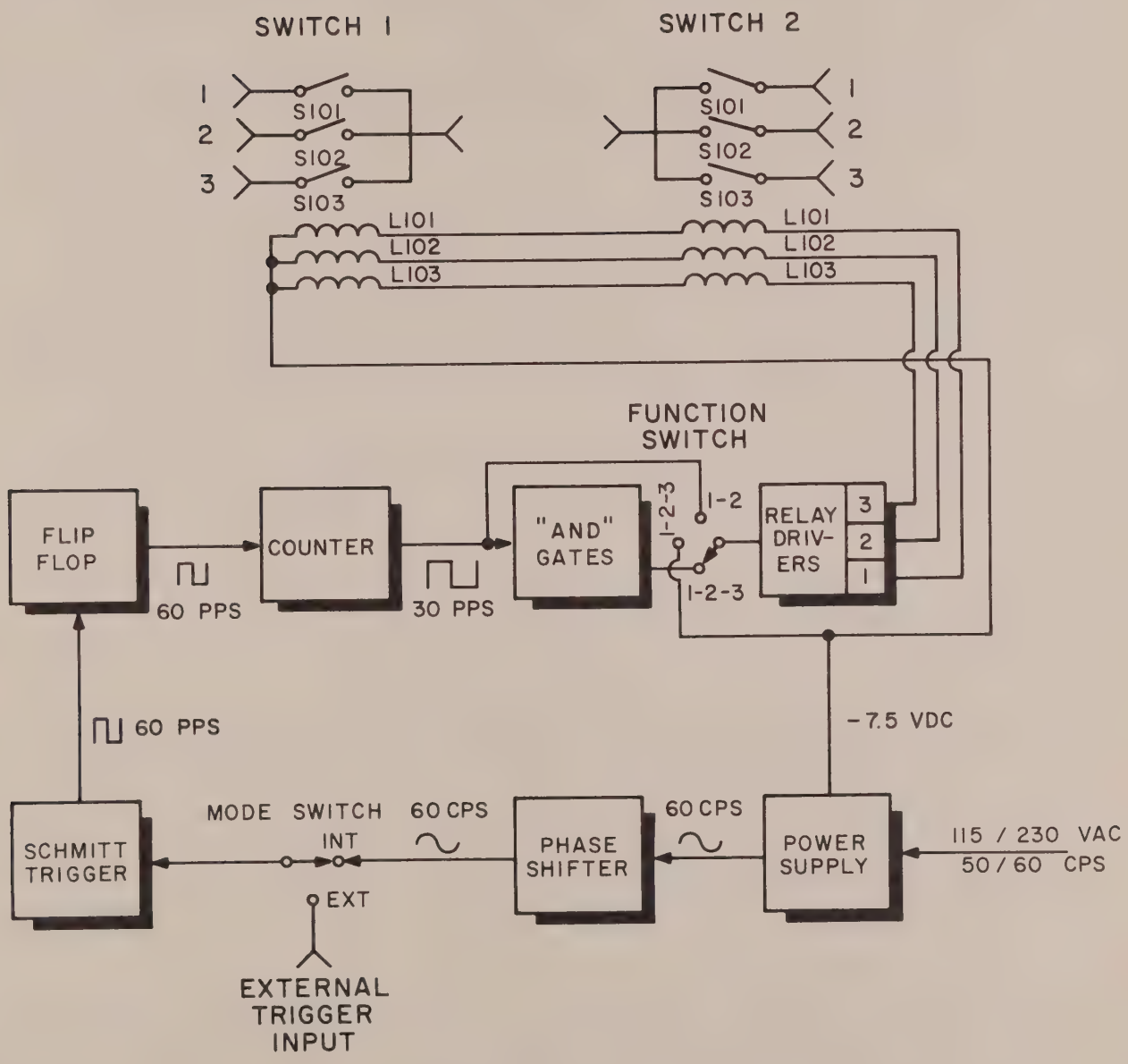


FIG. 4 MODEL TC-3, FUNCTIONAL BLOCK DIAGRAM

Q1 and Q2 do not function as a 2:1 counter when the TC-3 is employed in 2-way switching with external sync. In this mode, CR3 or CR4, depending on the desired sweep direction, is shorted by the MODE switch S2 and by FUNCTION switch S3. The circuit then operates at the sync frequency.

The signal at the collector of Q2 is applied through switch S3A to diodes CR6 and CR7 as the second input to AND gates CR5/CR6 and CR7/CR10. The collector signal at Q1 is applied through switch S3B to CR8 as the second input to AND gate CR8/CR9.

"AND" GATES, RELAY DRIVERS, AND RELAYS

1. AUTOMATIC TWO-WAY SWITCHING

When the FUNCTION switch is set to 1-2 position, the base of relay driver Q9 is grounded through contacts on switch S3B. This holds off Q9, preventing the contacts on switches S103 from closing, while Q7 and Q8 are switched on and off alternately by the output of the counter via contacts of S3.

To understand timing in automatic two-way switching, let us assume that the TC-3 is used in a test set-up for measuring the maximum response of a resonant circuit. Figure 10 can be used to illustrate such a set-up, if reference B is replaced with the circuit under test.

As timing in automatic two-way switching depends on the source of the sync signal, we shall first consider the case where an internal 60 cps (50 cps) synchronization source is applied.

In this condition Q1 and Q2 function as a 2:1 counter so that their collector pulses occur at a 30 pps (25 pps) rate. The timing diagram in figure 8 shows that Q8 starts to conduct at the beginning of the first sweep cycle and remains in this state for the duration of the full sweep cycle. This closes switches S102, connecting the circuit under test to the sweep generator and the detector. The circuit is swept during the trace half of the sweep cycle. Since the return trace is blanked, the output of the detector falls to zero and remains in that state during the blanking period, producing a zero line on the oscilloscope.

At the beginning of the next sweep cycle, Q8 is cut off and Q7 begins to conduct. This opens switches S102, closes switches S101, and connects the reference device (A) into the test circuit. Now, the reference device is swept during the first half of the sweep cycle and again, with the detector at zero during the second half of the sweep cycle, the return trace is blanked and a zero line is produced on the oscilloscope for the duration of blanking. The resulting oscilloscope display is illustrated in figure 6, relating all portions of the display to the timing diagram in figure 5.

Now we consider the case where an external sync signal is used in automatic two-way switching. Here the counter output has a 1:1 ratio; i. e., the circuit operates at the same frequency as the external sync signal.

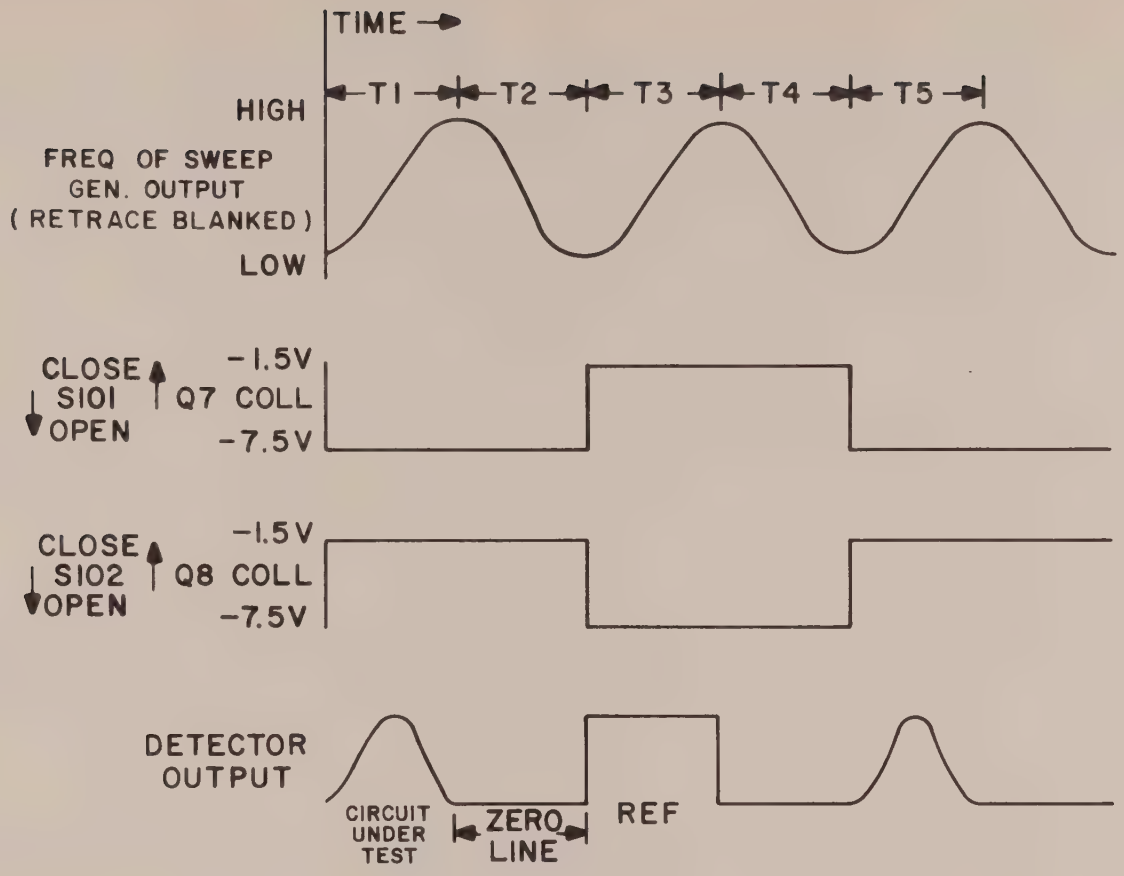


FIG. 5 TIMING DIAGRAM FOR TWO-WAY SWITCHING WITH INTERNAL SYNC

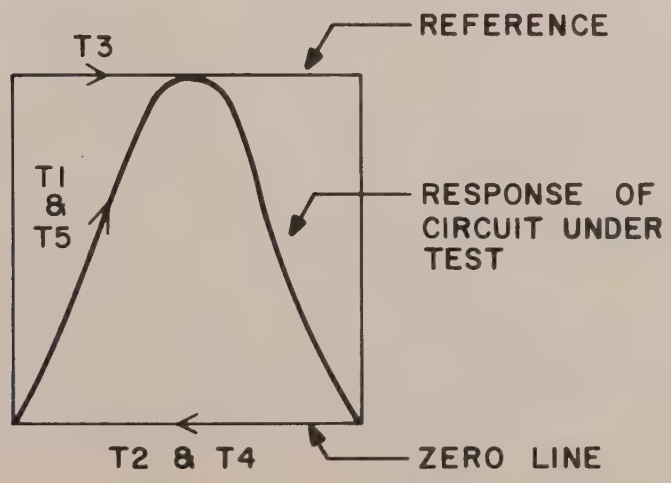


FIG. 6 TIMING AND DIRECTION OF DISPLAY COMPONENTS FOR TWO-WAY SWITCHING WITH INTERNAL SYNC

Figure 7 gives the timing diagram for this condition both during the forward and the reverse sweep. In the forward sweep mode Q8 is conducting during the first half (trace) of the sweep cycle, while Q7 is cut off. Switches S102 are closed during this period, connecting the circuit under test between the sweep generator and the detector. At the beginning of the second half (return trace) of the sweep cycle, Q8 is cut off, Q7 conducts, and switches S101 close while switches S102 open. This connects the reference device (A) into the test circuit while the device under test is disconnected. This sequence is repeated at the start of the next and all succeeding sweep cycles.

For the reverse sweep mode the sequence of events is the opposite of that occurring during the forward sweep mode. Figure 8 illustrates the oscilloscope displays for both forward and reverse sweep and the relationship of all portions of the displays to the timing diagrams in figure 7.

2. MANUAL SWITCHING

Withe FUNCTION switch S3 in position 1 or 2 or 3, power is applied through R27 and contacts on switch S3, turning on transistor Q7 or Q8 or Q9. The other two drivers are held off because their bases are grounded through S3.

3. AUTOMATIC THREE-WAY SWITCHING

With the FUNCTION switch S3 in position 1-2-3, the AND gates come into play. Figure 9 gives the timing diagram for the AND gates and their relationship to the relay drivers. If either or both inputs to a gate are at -0.5 volts, one or both diodes conduct, making the base of the associated relay driver slightly positive with respect to the emitter. Under these conditions the driver is cut off, no current flows through the relay coils and the relay contacts are held open.

When both inputs to the gate fall to -6 volts, both diodes are cut off, the driver base goes negative with respect to the emitter and the transistor conducts. Now current flows through the relay coils and contacts close.

Figure 10 illustrates a typical three-way switching set-up for the apparent simultaneous display of the maximum response of a resonant circuit, the upper limit reference (A), and a 3 db down reference (B).

Figure 11 diagrams the relationship between the sweep output and switching; Figure 12 shows the resulting oscilloscope presentation.

At the start of the first half (trace) of an initial sweep cycle switches S101 close and connect reference A into the test circuit. During this period switches S102 and S103 are

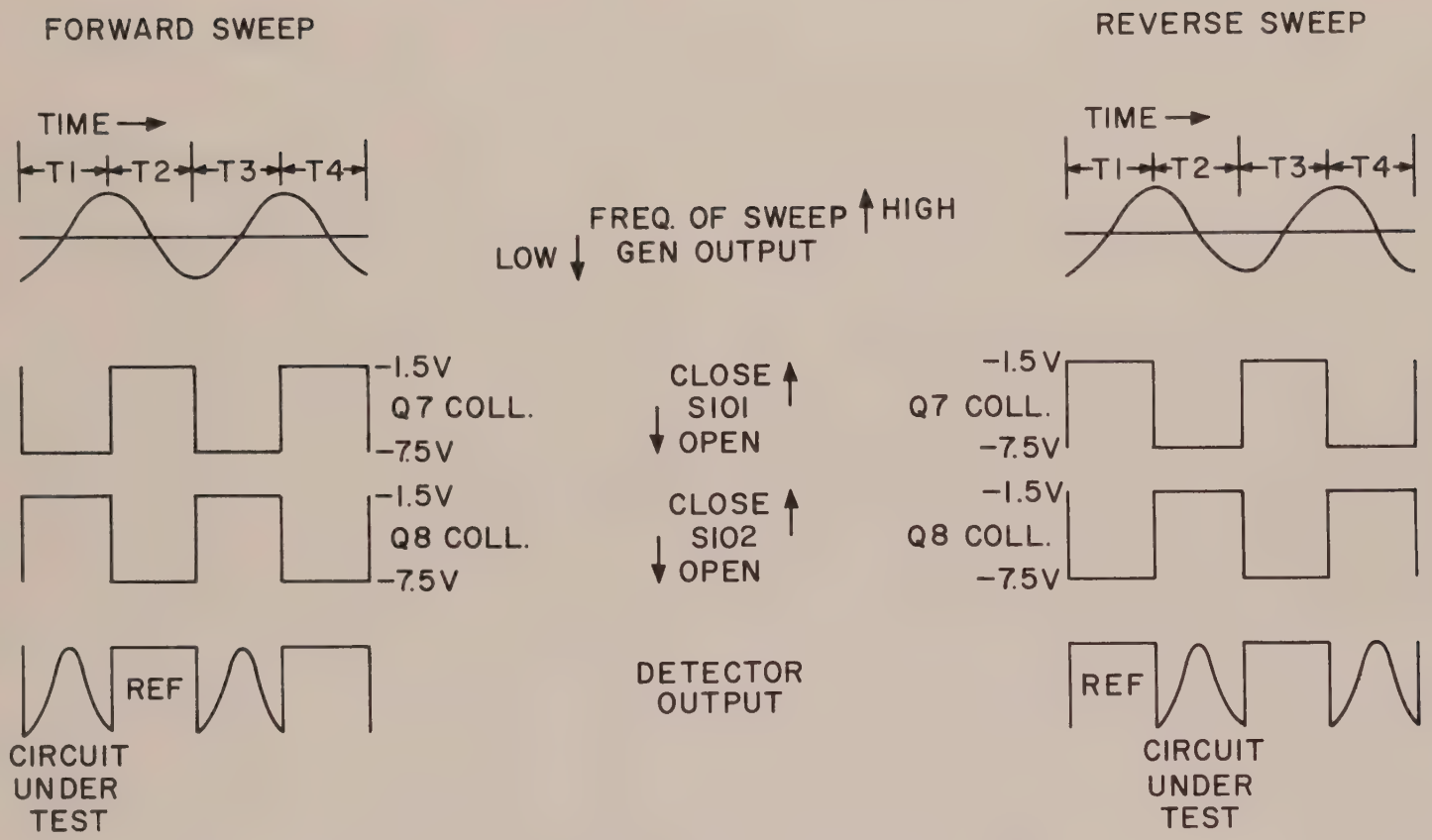


FIG. 7 TIMING DIAGRAMS FOR TWO-WAY SWITCHING WITH EXTERNAL SYNC

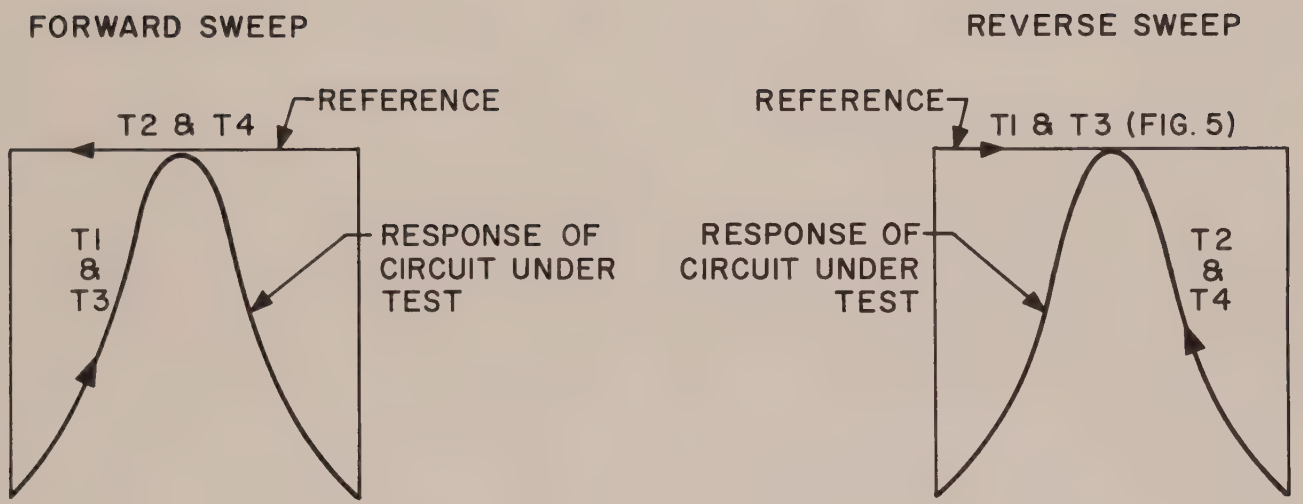


FIG. 8 TIMING AND DIRECTION OF
DISPLAY COMPONENTS FOR TWO-WAY SWITCHING
WITH EXTERNAL SYNC

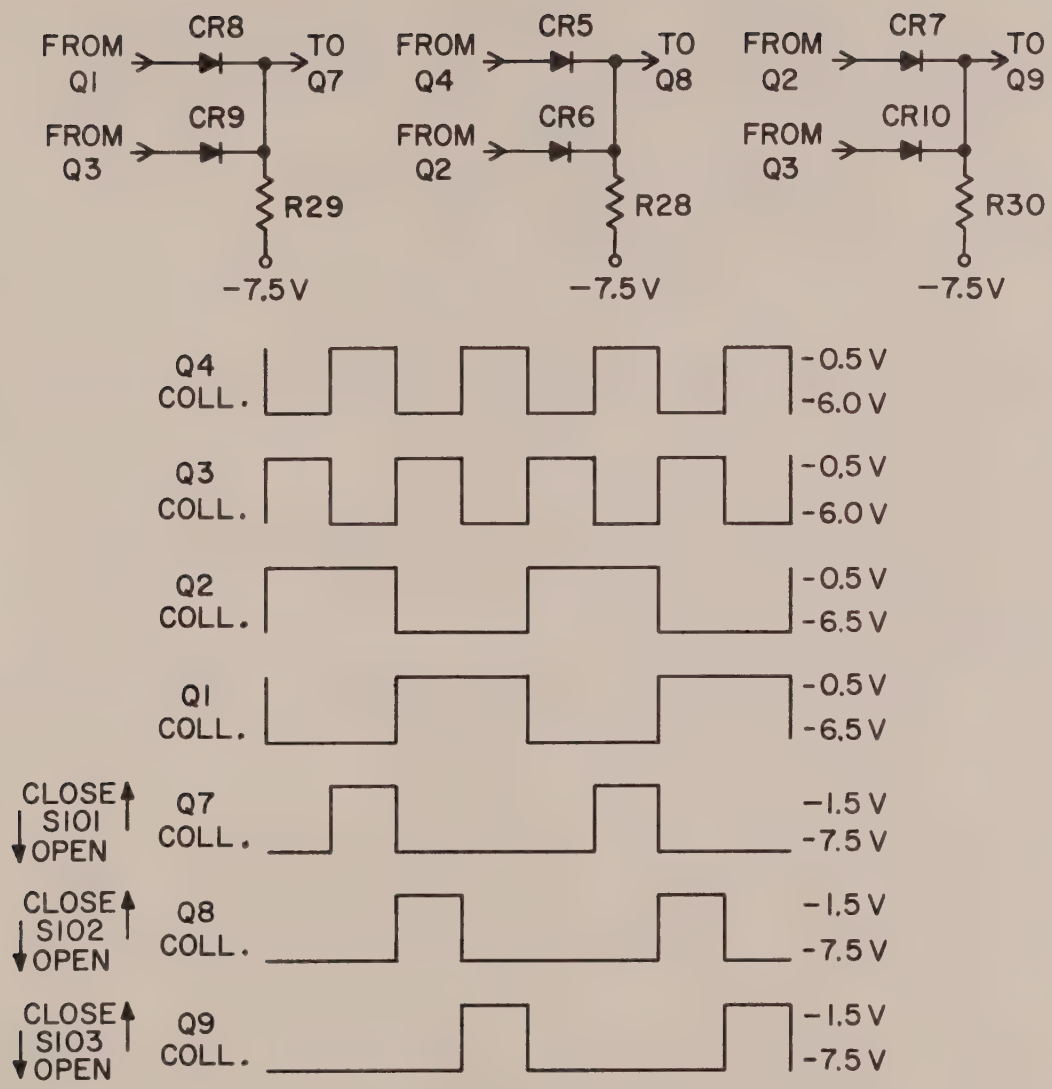


FIG. 9 TIMING DIAGRAM FOR THREE-WAY SWITCHING

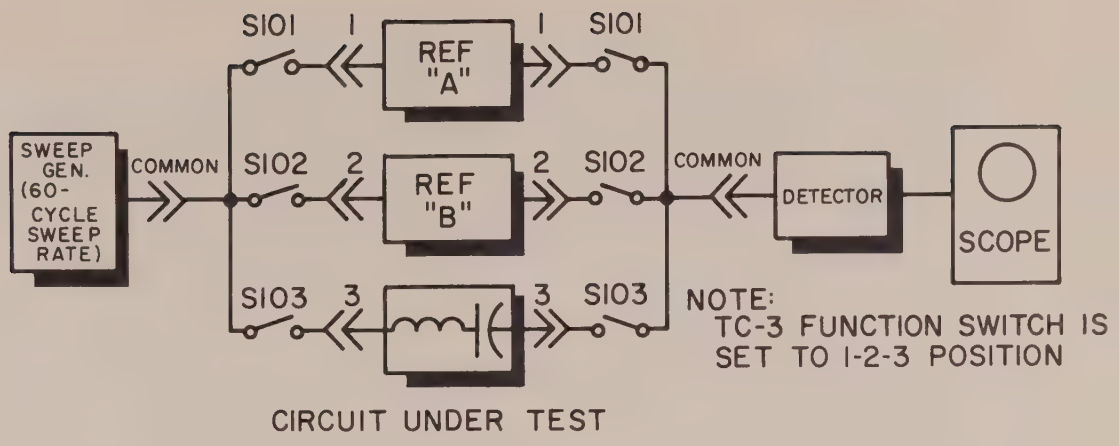


FIG. 10 TYPICAL SET-UP FOR THREE-WAY (1-2-3) SWITCHING

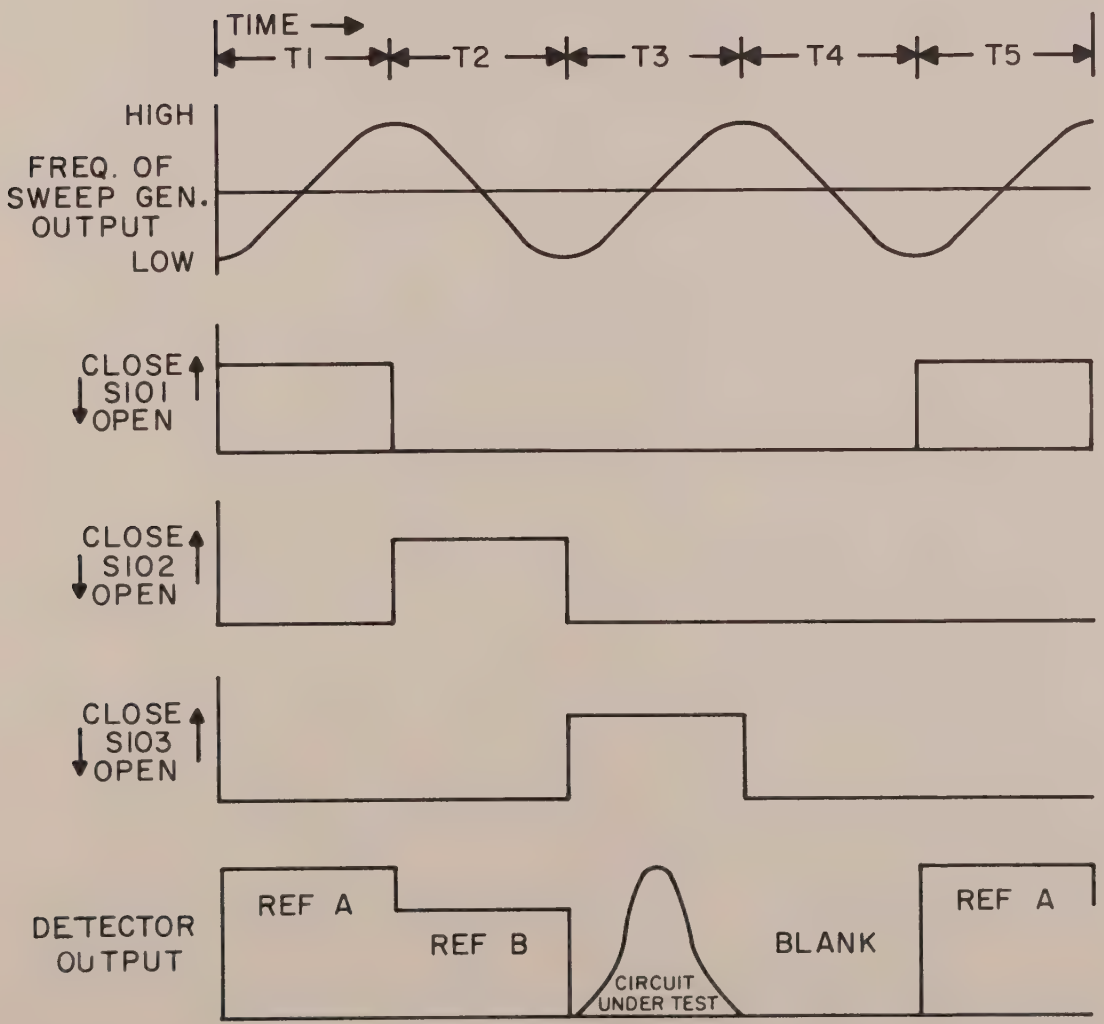


FIG. 11 TIMING RELATIONSHIPS FOR THREE-WAY SWITCHING

open. Starting the second half (return trace) of the sweep cycle, switches S101 open and switches S102 close, while switches S103 remain closed. This connects the second reference (B) into the test circuit for the return trace period. Finally, at the start of the first half (trace) of the second sweep cycle, switches S101 remain open, switches S102 open and switches S103 close. This connects the circuit under test for the duration of the trace, while reference A and reference B are disconnected. During the period of retrace in the second sweep cycle, all switches remain open and a zero line is produced on the oscilloscope. Then the entire sequence of switching is repeated.

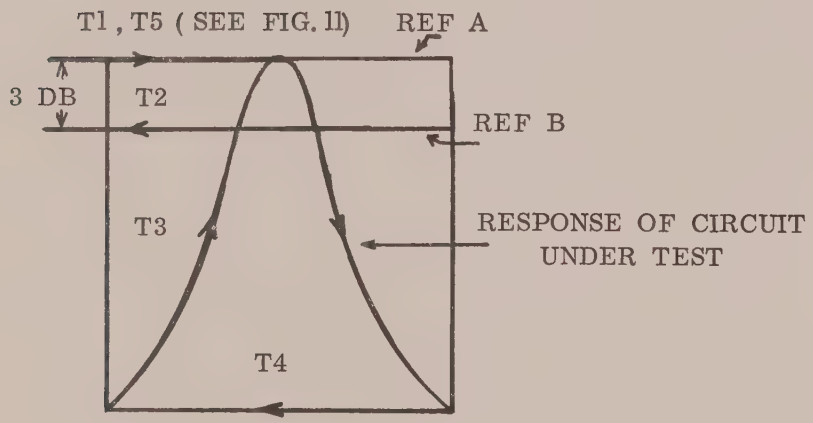


FIG. 12 TIME AND DIRECTION DIAGRAM OF DISPLAY COMPONENTS FOR THREE-WAY SWITCHING

MAINTENANCE

Model TC-3 is designed to give long, trouble-free service. Repairs should only be made be personnel familiar with solid-state circuitry. The schematic circuit diagram and replacement parts list will be an aid in servicing.

If for some reason the unit cannot be repaired in the field, the instrument may be returned to the Jerrold Laboratory, Byberry Rd. and the Penna. Turnpike, Hatboro, Penna. After notifying Jerrold of your intention to return the unit for repair, carefully pack the unit and ship it (with freight and insurance prepaid) together with a note stating the serial number of the unit and listing the difficulties encountered. The instrument will be repaired free of charge under conditions of the Warranty. Otherwise, it will be repaired and returned at nominal charges.

Jerrold Warranty Form 453-002.1 applies.

REPLACEMENT PARTS LIST 3-WAY COAXIAL COMPARATOR
MODEL TC-3

ASSEMBLY REF. DWG. NO.: 861-601

ITEM	SCHEMATIC DESIGNATION	QTY	DESCRIPTION	JERROLD PART NO.
			CAPACITORS	
1	C1	1	10 uf, 64 v, electrolytic	127-064
2	C2	1	1600 uf, 10 v, electrolytic	127-073
3	C3-6	4	0.1 uf, 200 v	125-002
4	C7	1	0.25 uf, 200 v	125-008
			CONNECTORS	
5	J1, 101 (2), 102 (2), 103 (2), 104 (2)	9	Receptacle, BNC	183-216
6	J2, 3	2	Socket, 7 pin	181-150
			FUSE	
7	F1	1	3AG, 250 v, 1 amp	101-238
			PILOT LIGHT	
8	DS1	1	Lamp, neon miniature	102-513
			RECTIFIERS	
9	CR1, 2	2	Silicon	137-709
10	CR3, 4	2	Crystal	139-100
11	CR5-13	9	Silicon	137-718
12	CR14, 15	2	Silicon	137-712
			RESISTORS	
13	R1	1	33K, 5%, 1/2 w	112-548
14	R2	1	10K, 10%, 2 w, potentiometer	118-132
15	R3, 3, 18	3	200 Ω, 5%, 1/2 w	112-272
16	R5, 6, 12, 13, 27	5	2K, 5%, 1/2 w	112-398
17	R7, 8, 15, 16	4	10K, 5%, 1/2 w	112-485
18	R9, 17, 34, 35, 36	5	10 ohm, 5%, 1/2 w	112-107
19	R10, 19, 23	3	15K, 5%, 1/2 w	112-506
20	R11, 14	2	510 ohm, 5%, 1/2 w	112-236
21	R20, 22, 26, 28-33	9	1K, 5%, 1/2 w	112-359
22	R21	1	4.7K, 5%, 1/2 w	112-443
23	R24	1	36K, 5%, 1/2 w	112-557
24	R25	1	20K, 5%, 1/2 w	112-524

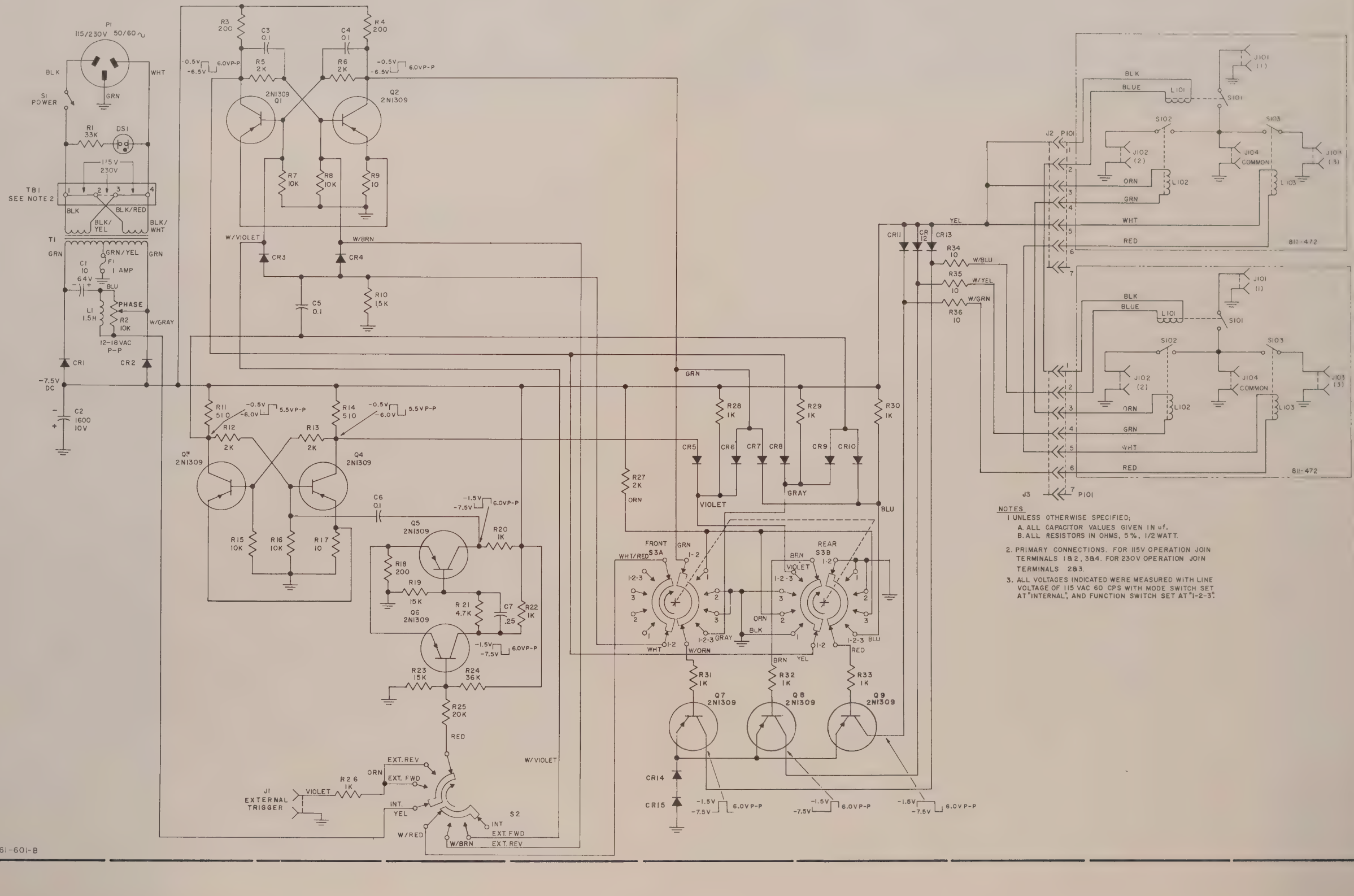
REPLACEMENT PARTS LIST

ASSEMBLY REF. DWG. NO.: 861-601

ITEM	SCHEMATIC DESIGNATION	QTY	DESCRIPTION	JERROLD PART NO.
			SWITCHES	
25		2	Coaxial switch assembly	811-472
26	S1	1	Toggle, spst	162-001
27	S2	1	Wafer, 3 position	161-145
28	S3	1	Wafer, 5 position	161-146
			TRANSFORMER	
29	T1	1	Power	141-209
			TRANSISTORS	
30	Q1-9	9	2N1309, RCA	130-127

SCHEMATIC

TRANSISTORIZED COMPARATOR
MODEL TC-3



NOTES

1 UNLESS OTHERWISE SPECIFIED;
A. ALL CAPACITOR VALUES GIVEN IN uf.
B. ALL RESISTORS IN OHMS, 5%, 1/2 WATT.

2. PRIMARY CONNECTIONS. FOR 115V OPERATION JOIN TERMINALS 1&2, 3&4. FOR 230V OPERATION JOIN TERMINALS 2&3.

3. ALL VOLTAGES INDICATED WERE MEASURED WITH LINE VOLTAGE OF 115 VAC 60 CPS WITH MODE SWITCH SET AT "INTERNAL", AND FUNCTION SWITCH SET AT "1-2-3".

E861-601-B

JERROLD

Technical Newsletter

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INDUSTRIAL PRODUCTS DIVISION EDITOR: G. RATH

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COMPARISON TECHNIQUE
IMPROVES SWEEP FREQUENCY MEASUREMENTS*

By K. A. SIMONS, Chief Engineer, Jerrold Electronics Corporation

The Jerrold Electronics Corporation maintains a Design Engineering Laboratory at Hatboro, Pennsylvania. The primary function of this organization is the design of electronic equipment, including wide-band amplifiers, filters and associated equipment in the "awkward" frequency range between 5 and 220 mc. This range is called awkward because the upper end is too high for measuring methods suitable for the low communications frequencies, and the lower end is too high for standing-wave line measurements. A number of measuring techniques, developed to meet this situation, are described in this article.

*A major part of this article appeared first under the title "SWEEP MEASUREMENTS MAKING THE TOUGH ONES EASY" in "electronics" Vol. 36, No. 16, April 19, 1963.

BASIC COMPARISON CIRCUIT

The basic technique is to compare transmission through two paths. Figure 1 shows the method used to determine accurately the transmission loss through a network. A test signal source and an output indicator are connected to a DPDT switch so that in one switch position (TEST) the signal is passed through the network the loss of which is to be measured, and in the other switch position (REFERENCE) it is connected through a variable calibrated attenuator.

To make a measurement, the operator throws the switch repeatedly back and forth, while adjusting the attenuator until the output indicator shows identical responses for both switch positions. The loss in the tested network is then equal to that of the attenuator and can be read off from its calibration.

This technique has been used for many years for precise transmission measurements in the telephone art. (See, for example, the article "Transmission Measuring for Manufacture," by George W. Pentico in THE WESTERN ELECTRIC ENGINEER, October, 1961.)

The technique has some of the basic advantages of the more familiar null-bridge measuring method, namely:

1. High source output and a sensitive indicator make very precise settings possible.
2. Other characteristics of the source and indicator have little effect on the accuracy of the result. Neither needs to be calibrated, and the amplitude stability need only be constant long enough for a comparison to be made.
3. Calibration accuracy is entirely determined by a convenient passive attenuator.

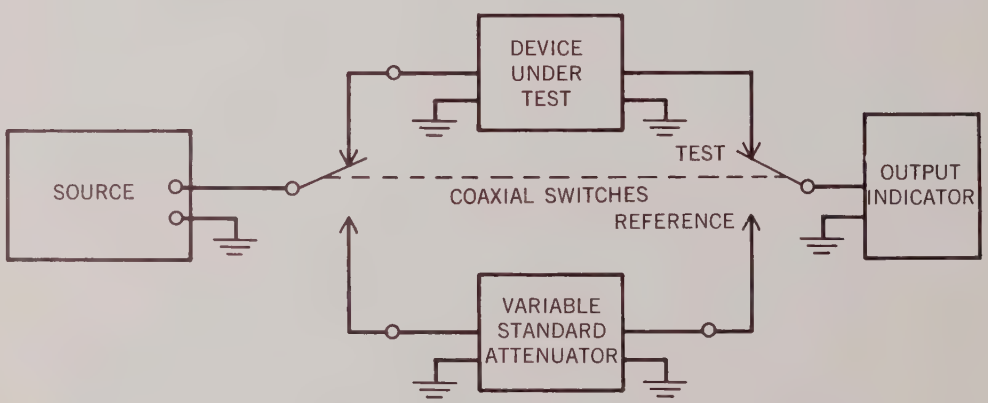


Fig. 1

COMPARISON WITH SWEEP DISPLAY

This approach is a "natural" for sweep frequency testing over wide frequency bands. Sweep frequency generators and oscilloscopes are notoriously as poor on calibration as they are good on sensitivity, while stable and accurate attenuators are common. To adapt to the sweep situation, the basic technique is modified in two respects:

1. High frequency measurements necessarily involve coaxial transmission lines; thus the comparison switch, as part of the transmission system, must be coaxial with an impedance matching that of the associated lines.
2. Oscilloscopic display of a sweep frequency response curve requires periodic repetition of the measurement (usually 60 times per second) so the eye can see a steady pattern. The "switch" must also operate period-

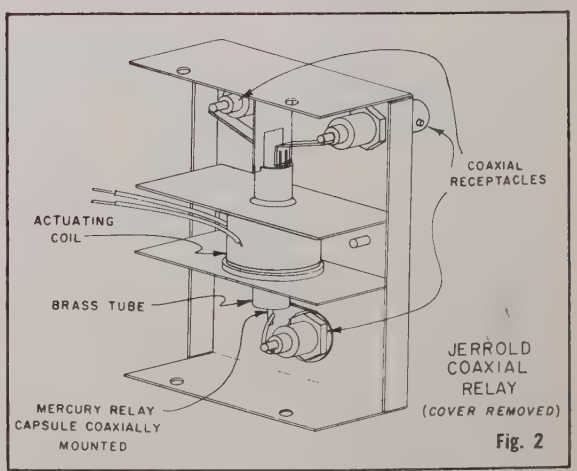


Fig. 2

ically so that the calibration may be seen as part of this stationary pattern. To achieve periodic switch operation, a high speed coaxial relay is used. The construction is illustrated in Figure 2. A Clare mercury-wetted relay capsule is mounted so that it forms a well-matched coaxial structure. This unit operates at high speeds (up to 60 cps) with no bounce and with very long life.

Switches have been in full-time operation in our laboratory for five years with negligible failures.

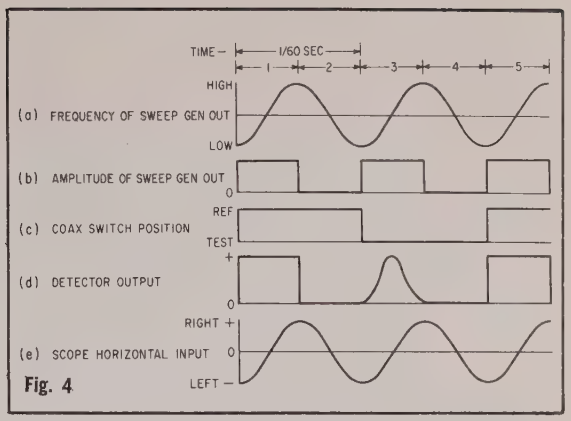


Fig. 4

MEASURING LOSS BY COMPARISON

The test set-up for measuring and displaying the high frequency loss of a network by the sweep-frequency comparison method is diagrammed in Figure 3. The output of a Sweep Frequency Generator, sweeping across the desired band at a 60-cycle rate, is connected to one of two SPDT coaxial switches. The other switch is connected to the input of a wide-band detector. The switches transmit alternately through the network under test and through the variable attenuator.

When this detector output is applied to an oscilloscope's vertical input terminals, and a voltage, with its instantaneous magnitude phased to match the instantaneous frequency of the generator, is applied to the horizontal output terminals, the scope traces out the display illustrated in Figure 4f. (In the example shown, the horizontal deflecting voltage must be a 60-cycle sine-wave phased as shown, to agree with the waveform and phase of the frequency modulation.)

The curve presents the loss as it varies with frequency in the unit under test, together with a base line showing zero response (infinite loss) and the REFERENCE trace showing the loss corresponding to the attenuator setting.

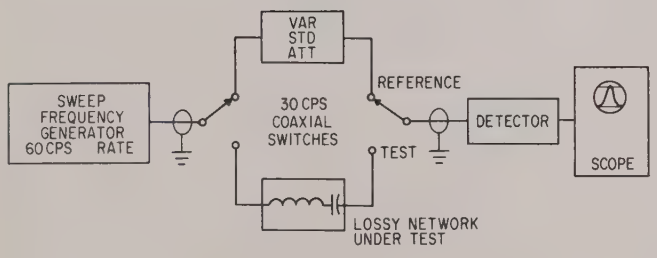


Fig. 3

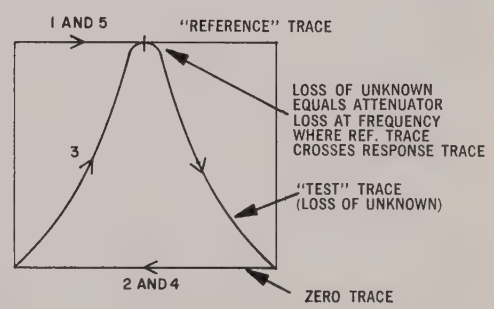

1 AND 5
"REFERENCE" TRACE
LOSS OF UNKNOWN EQUALS ATTENUATOR LOSS AT FREQUENCY WHERE REF. TRACE CROSSES RESPONSE TRACE
3
"TEST" TRACE (LOSS OF UNKNOWN)
2 AND 4
ZERO TRACE
Fig. 4f

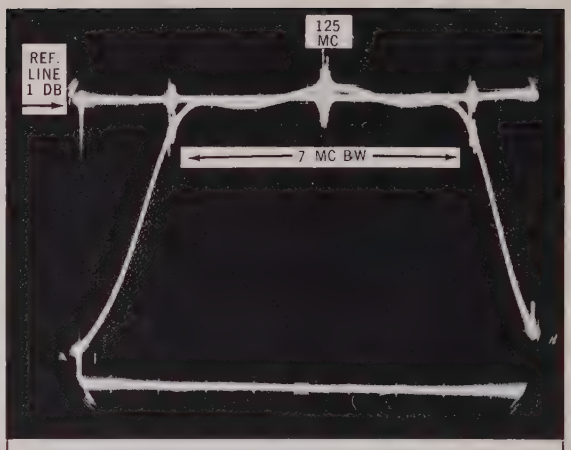
Figure 4 illustrates the manner in which the display is generated. The frequency of the sweep output varies sinusoidally between an upper and a lower limit (Figure 4a) at a 60-cycle rate. The output is cut off during the return trace (Figure 4b) to form a zero reference trace. The coaxial switches are transferred at a 30-cycle rate (Figure 4c) allowing the development of a full trace in the REFERENCE position followed by a full trace in the TEST position. As a result, the detector output (Figure 4d) goes through four conditions in each thirtieth of a second; first indicating reference output, second delivering zero output, third following the loss curve of the unit under test and fourth repeating the zero output trace.

The REFERENCE trace crosses the TEST trace at those frequencies where the loss of the unit under test precisely equals the loss of the standard attenuator.

The scope trace photograph in Figure 5 shows the insertion loss measurement of a triple-tuned band-pass filter. The attenuator was set at 1.0 db and the point at which the REFERENCE trace crosses the response shows a loss of 1.0 db at a 7-mc band-width centered on 125 mc. It is a major advantage of this presentation that the accuracy of the measurement is not affected by the constancy of the sweep output across the band, the flatness of the detector, or by drift or other changes in scope gain and centering.

In cases where very small attenuation differences are to be observed, it is convenient to increase the vertical gain and recenter the trace to show a highly expanded view of part of a response pattern. This is illustrated in the series beginning with Figure 6. A Jerrold 900-B sweep frequency generator was set to sweep between zero and 200 mc, and a short coaxial jumper was connected between its output and a detector. The scope vertical gain was increased to about four times that required to show the change from zero to full output, and the centering readjusted to bring the resulting trace onto the screen.

Under this condition the screen showed a change of only 0.2 db per division and the resulting trace (Figure 6) shows the sweep output to be constant within ± 0.2 db. With the same sweep and scope settings, the sweep output was then connected through two coaxial switches (Jerrold Model FD-30) transferring between a short jumper and a variable attenuator (Jerrold Model AV-50) connected through two 2-foot coaxial cables.



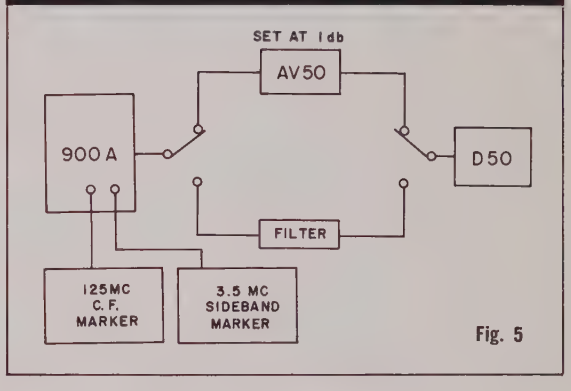


Fig. 5

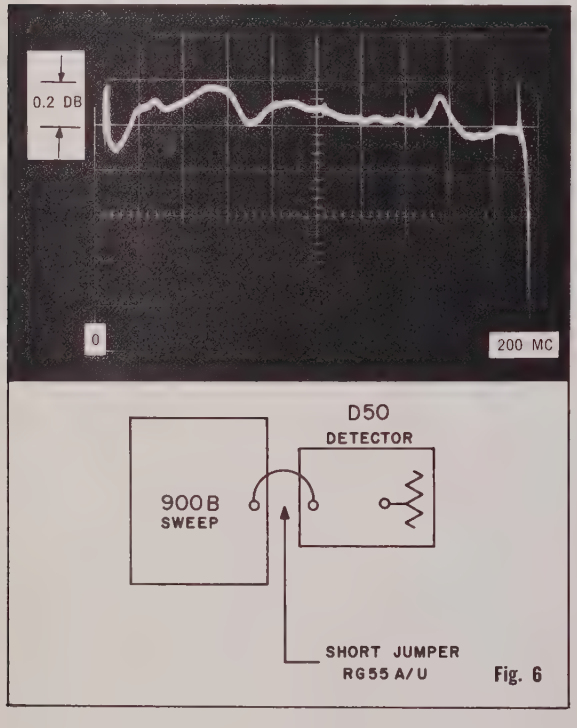
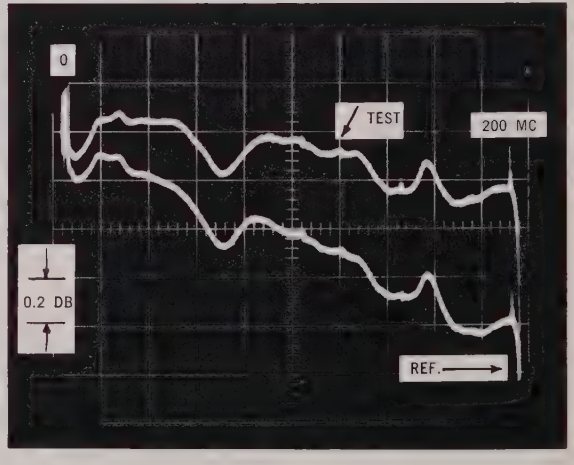


Fig. 6



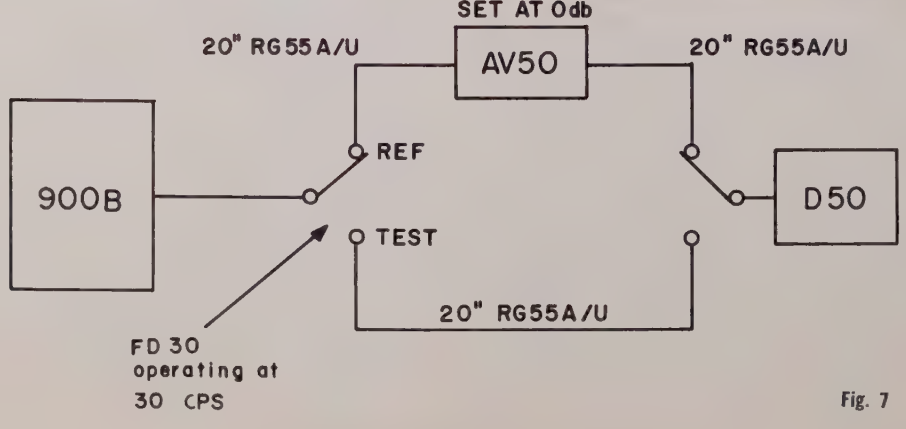


Fig. 7

The resulting photograph (Figure 7) compares the jumper loss with the attenuator insertion loss (at zero setting) continuing with the same expanded vertical scale. By careful inspection it can be seen that the TEST (upper) trace is slightly down at the high end (compared with Figure 6) indicating that the coaxial switches and short jumper have added about 0.2 db loss at 200 mc, while the REFERENCE (lower) trace shows that the attenuator and its longer cables have added about 0.8 db loss at the high end.

If precise measurements are to be made it is **not** essential that either curve be precisely flat, but it **is** essential that the loss on the TEST side, before inserting the unknown, be the same as that on the REFERENCE side. This condition was satisfied by inserting additional cable on the TEST side (totalling 137 inches) so that the insertion losses in both circuits were close to identical. The resulting trace was photographed (Figure 8a) and shows considerably less than 0.05 db difference between the two circuits over the whole frequency range from low frequencies up to 200 mc. Inserting an additional 0.5 db into the standard attenuator gave the result illustrated in Figure 8b, showing that this set-up could be used for loss measurements involving very small attenuation differences.

Figure 9 shows how this approach was applied to a practical measuring problem. We wanted to test a repeater amplifier designed for long cascaded runs in television distribution systems. The amplifier, together with its equalizer, is required to have gain equalizing as closely as possible the loss of 2000 feet of a particular coaxial cable between the frequencies of 5 and 95 mc. To test this, the cable, the equalizers and the amplifier were connected, each following the other on the TEST side of the comparison circuit, with a jumper providing a zero loss reference on the REFERENCE side. The resulting response (illustrated in Figure 9b) shows that the combination of cable plus equalizer plus amplifier had zero loss within about $\pm$ 0.25 db between 5 and 95 mc. The fine grained ripple is primarily due to variations in the cable's transmission characteristic.

The usefulness of this technique is obvious, first in the fact that it would take many hours to make this measurement using point-by-point techniques and even then the accuracy would be questionable, and second in the fact that the necessary refined adjustments of the equalizer and amplifier can be carried out quickly and accurately while observing the display, which could not be done with a point-by-point approach.

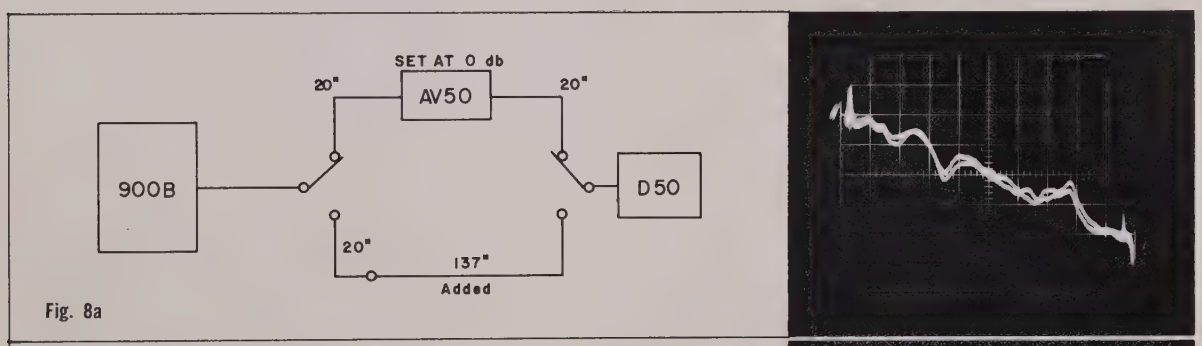


Fig. 8a

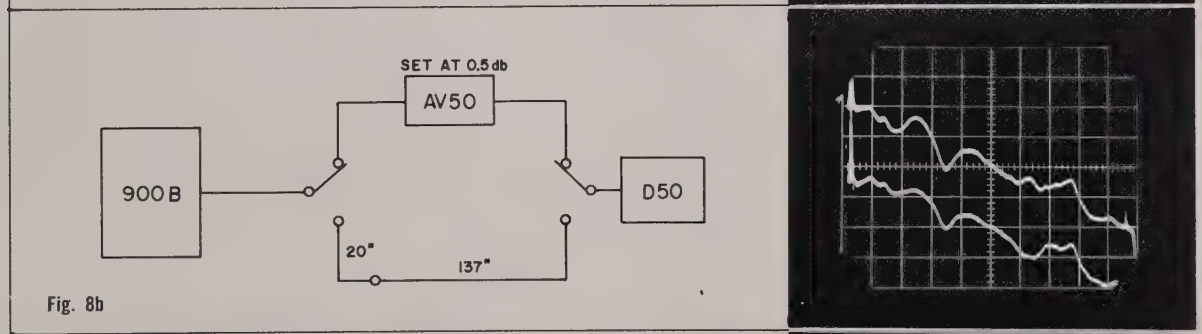


Fig. 8b

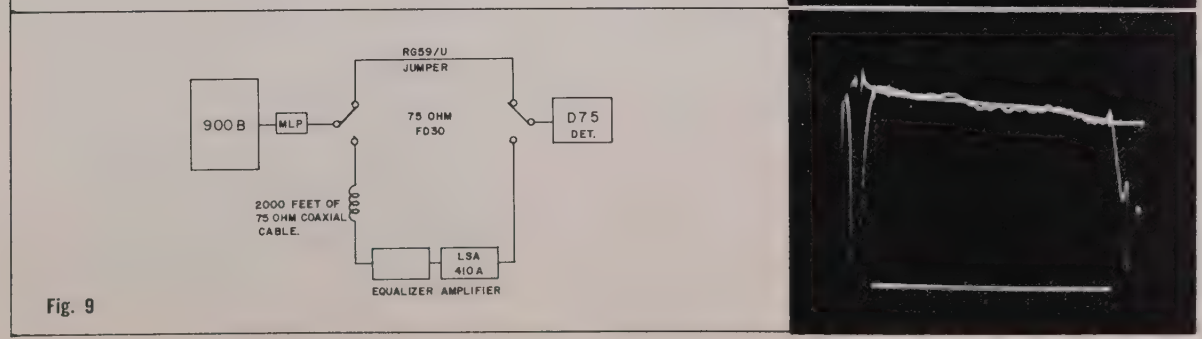


Fig. 9

MEASURING GAIN BY COMPARISON

The comparison technique can be used effectively for the measurement of amplifier gain. The basic circuit is diagrammed in Figure 10. By using a jumper as a zero loss reference and inserting the variable attenuator ahead of the amplifier on the TEST side, the REFERENCE line is made to cross the amplifier response curve at the point where the attenuator loss equals the amplifier gain. The resulting display is illustrated in Figure 11.

The photographs in Figure 12 illustrate gain measurement on an amplifier designed to pass television channel 13 for use in rf distribution systems. Figure 12a illustrates the response curve in the TEST position with a frequency marker at band center (213 mc). Figure 12b illustrates a useful frequency marking technique where a low frequency generator (3 mc) is connected simultaneously with a high frequency one and the resulting side-bands mark the channel edges (213 ± 3 mc). Figure 12c illustrates the trace with the coaxial switch running and the attenuator set at 57 db (0.5 db below the maximum amplifier gain).

To obtain a "blown-up" view of the pass band response, the scope gain was turned up and the trace recentered to give the result shown in Figure 12d. This shows that the amplifier response is within 0.1 db across the band. Neither the measurement, nor the alignment which preceded it, could be readily carried out by any single frequency measurement technique.

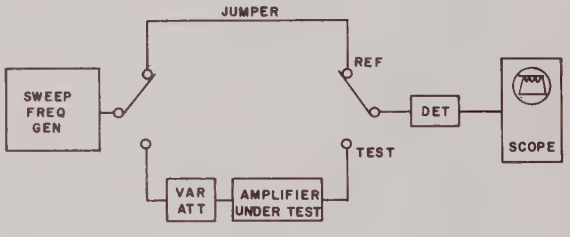


Fig. 10

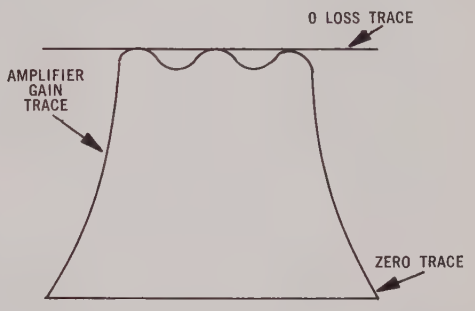
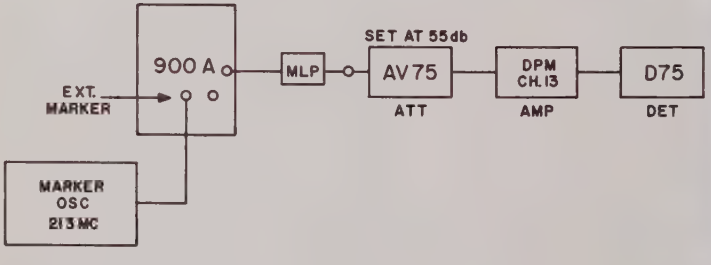


Fig. 11



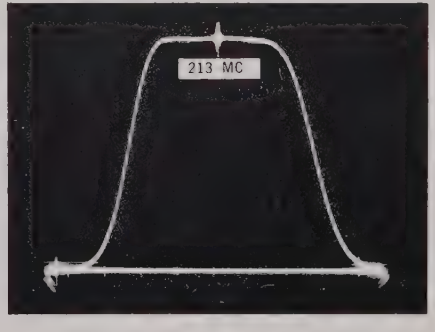
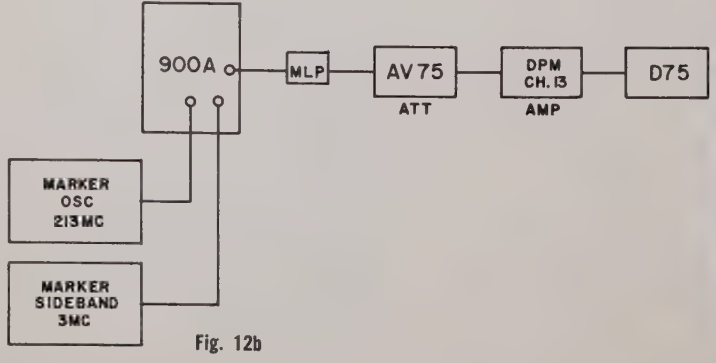


Fig. 12a



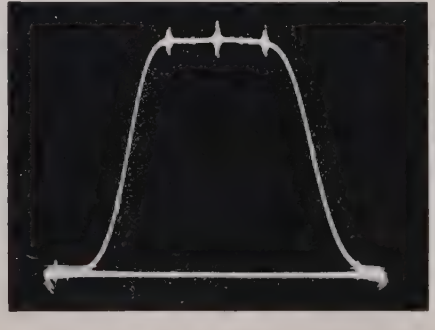


Fig. 12b

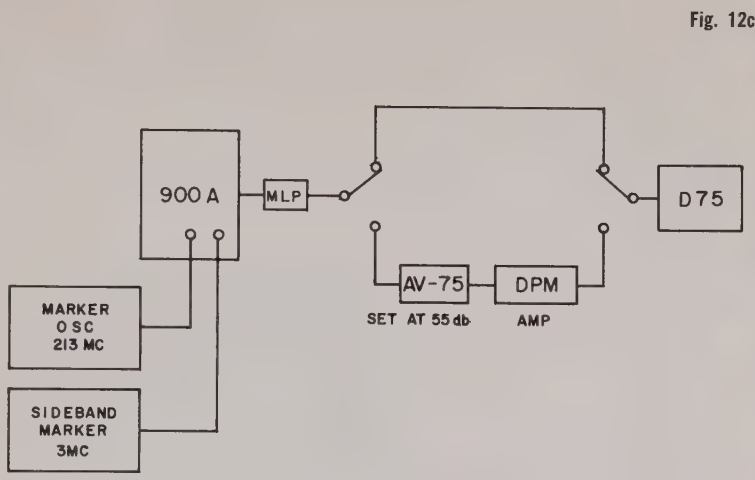
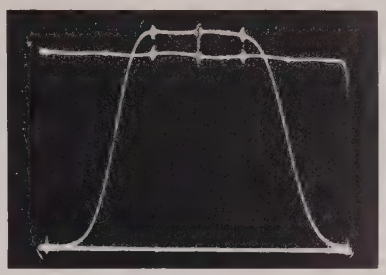


Fig. 12c



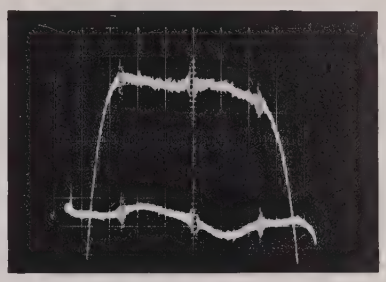


Fig. 12d

MEASURING IMPEDANCE MATCH BY COMPARISON

In addition to gain and loss measurements, a third application of the comparison method was found to be very useful in our laboratory. This involves employing a bridge circuit to provide wide-band display of impedance match characteristics. As described more fully in TNL, Vol. 1, No. 4, the technique depends on the characteristics of a high frequency bridge having six equal arms (including the impedance of the source and detector). The bridge circuit is diagrammed in Figure 13 and its effect is summarized by the fact that the insertion loss between the input and output terminals is equal to 12 db plus the return loss of that which is connected to the unknown terminal (return loss is the ratio of the reflected wave in a coaxial system to the incident wave, expressed in db). Stating this another way: when a signal is introduced into the input terminal of the bridge, the output signal **is** the reflected wave from the unknown diminished by 12 db.

Thus the bridge makes possible impedance measurements over a wide frequency band, converting impedance variations into loss variations which are then accurately measured by the comparison technique. It is, in effect, a directional coupler giving flat response over a very wide band of frequencies in the "awkward" 5 to 200 mc range. The equipment set-up for impedance sweeping is diagrammed in Figure 14. The bridge is connected to the TEST terminals of the comparison switches and a fixed 12 db attenuator is connected with the standard attenuator in the REFERENCE leg. To obtain adequate gain for the measurement of small reflections, a wide-band distributed amplifier is connected ahead of the detector. The display obtained is shown in Figure 14b, the REFERENCE trace crossing the unknown at a return loss level corresponding to the attenuator setting. The bridge we are now using allows measurement of return loss in the range 0 to 40 db, with an accuracy within $\pm$ 1 db.

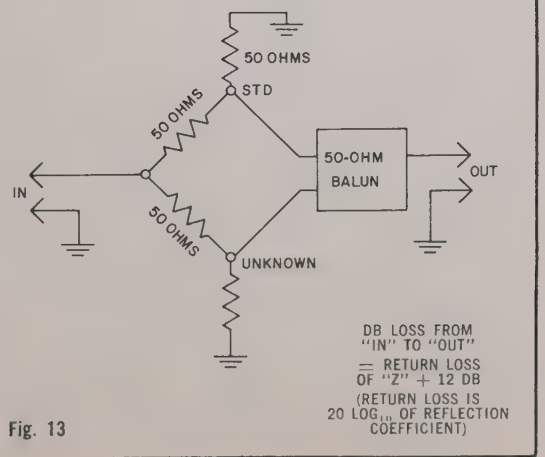


Fig. 13

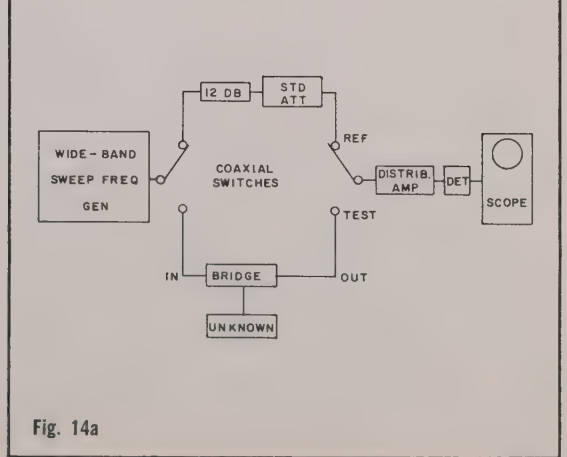


Fig. 14a

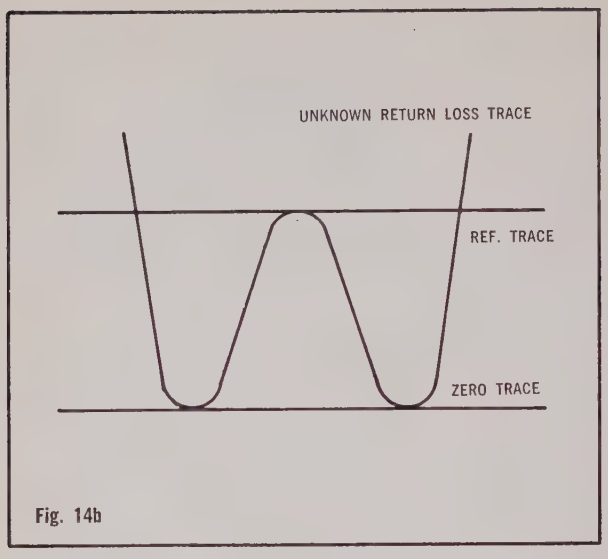


Fig. 14b

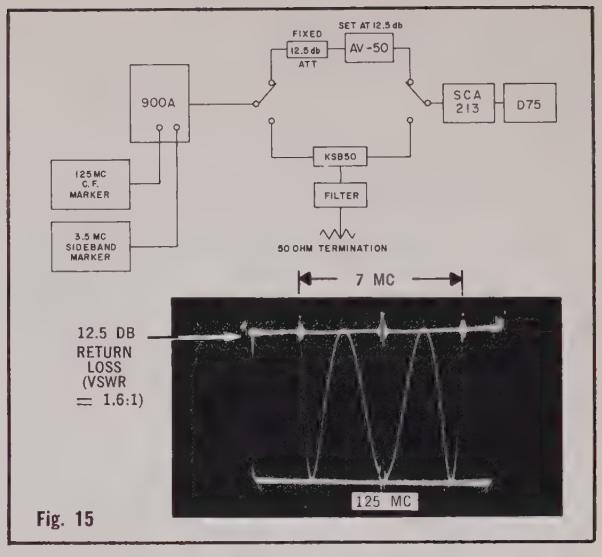


Fig. 15

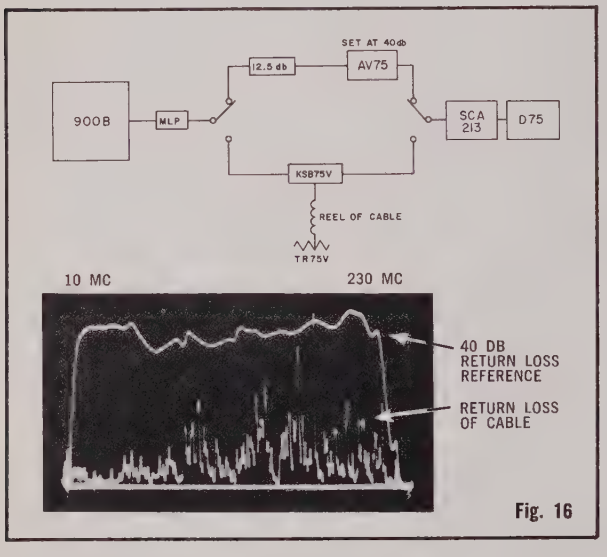


Fig. 16

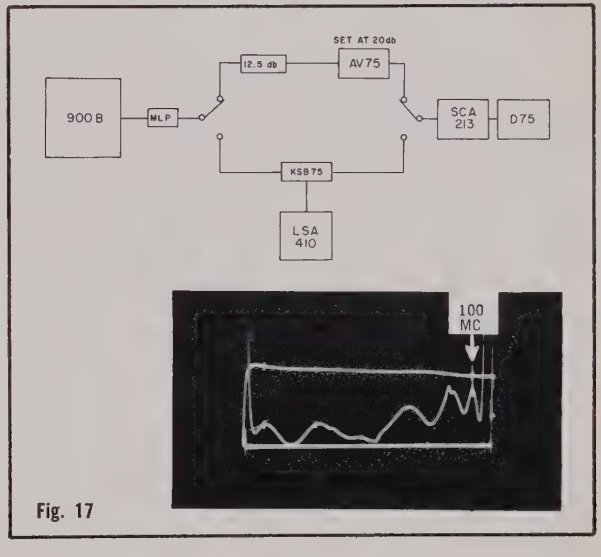


Fig. 17

Figure 15 illustrates measurement of the input impedance of the band-pass filter the insertion loss of which is shown in Figure 5. The filter was aligned for maximum return loss of 12.5 db (max. VSWR of 1.6:1) with Chebishev (equal ripple) match characteristics. Adjustment and measurement were carried out rapidly with the aid of the comparison presentation.

Figure 16 illustrates measurement of the "structural return loss" (the impedance variations due to minor mechanical irregularities) in a 1000-ft. piece of unusually good coaxial cable. The maximum reflection spike at about 150 mc had a return loss level just over 40 db.

Measurement of such a complex characteristic over this frequency range would be a maddening (if not impossible) process by any point-by-point technique.

Figure 17 illustrates the impedance match at the output terminal of the amplifier the response of which was shown in Figure 9. Without the rapid and accurate measurement of match made possible by the return loss bridge, production alignment of this amplifier to meet the required overall performance would be impossible.

CONCLUSION

The comparison technique has been described as it is used at the Jerrold Laboratory for measurement of loss, gain, and impedance match, simultaneously with sweep frequency display of these characteristics. This technique has been found absolutely indispensable in the speed and convenience it contributes to the design and adjustment of a variety of devices in the "awkward" frequency range between 5 and 220 mc.

NOTE — Additional copies of this paper and engineering assistance on the application of Measurements By Comparison may be obtained by contacting the Industrial Products Division, Jerrold Electronics Corporation, 15th & Lehigh, Phila., Pa. 19132. Phone: BAldwin 6-3456 — Ext. 215.

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JERROLD

Technical Newsletter

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INDUSTRIAL PRODUCTS DIVISION

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NEW ATTENUATOR AND COMPARATOR

EXTEND FREQUENCY RANGE OF COMPARISON TECHNIQUE TO 1200 MC.

Fig. 2—Model ATV-109R Rack-Mounting Bank of Turret Attenuators

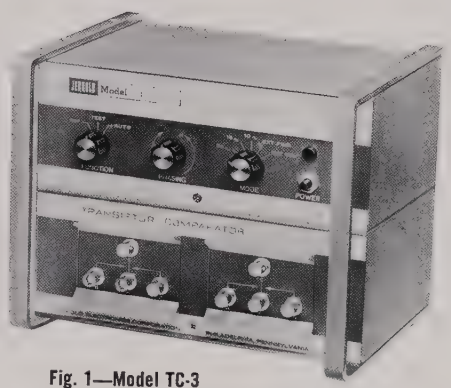


Fig. 1—Model TC-3 Coaxial Comparator

SUMMARY: A new drum attenuator and a transistorized three-way coaxial comparator are described, which allow accurate sweep-frequency measurements of transmission loss, gain, and reflection coefficient in 50-ohm coaxial systems from DC to 1200 MC.

INTRODUCTION

For the past six years, Jerrold has been offering as accessories to the 900-A and 900-B Sweep-Frequency Generators a comparator (high speed coaxial switch Model FD-30) and variable attenuators (Model AV-50). When used with a wide-band sweep-frequency generator these allow quite accurate measurements of transmission gain and loss[1], and when used with a suitable bridge, measurement of reflection coefficient (return loss)[2] to a limit of accuracy determined by the characteristics of these accessories. The FD-30 Comparator and the AV-50 Attenuator were originally designed for use in the frequency-range up to 250 MC, where they had excellent characteristics, with reasonably good performance up to 500 MC. Since the Model 900 Sweep Generators provide coverage up to 1200 MC there has been a need for improved accessories, making the comparison technique available up to the limit of the sweep capability.

The new Model TC-3 Transistorized Comparator and the Model ATV Turret Attenuators have been developed to meet this need. They provide measurement accuracy up to 1200 MC, somewhat better than that obtained with the older equipment up to 250 MC, and in addition feature several marked improvements in operating convenience over the older equipment.

1. Jerrold Technical Newsletter Volume 2, Number 1—March 1964. COMPARISON TECHNIQUE IMPROVES SWEEP FREQUENCY MEASUREMENTS. Ken Simons, Jerrold Electronics Corporation.

2. Jerrold Technical Newsletter Volume 1, Number 4—August 1960. A BRIDGE METHOD OF SWEEP FREQUENCY IMPEDANCE MEASUREMENT. (Same author.)

Figure 1 shows the Model TC-3 Coaxial Comparator. It consists of two basic housings arranged so that they can be mounted one on top of the other to form a convenient package for bench-mounting, or mounted side-by-side to form a 3½" high panel in a standard 19" rack. One of the units houses the transistor driver and the controls; the other houses the two coaxial switch assemblies. Each switch assembly consists of three reed relays mounted to form a single-pole triple-throw coaxial switch.

At frequencies in the gigacycle region, jumper cables present a major limitation on the accuracy of measurements. Therefore, accuracy is greatly improved if jumper lengths are kept to an absolute minimum. For this reason each assembly switch has been designed so that it can be removed from the housing and extended on a long cable so that it can be placed immediately adjacent to the units being tested. The reed relays operate equally well in any position; thus the switching heads can be positioned to suit the physical position of the units under test.

The operation of the new comparator can best be explained by comparing it with the FD-30. Figure 3a illustrates application of the FD-30 to the measurement and display of the frequency response of a resonant network. The sequence of operations when the unit is used with a 60-cycle supply is illustrated in Figure 3b and the resulting scope trace is shown in Figure 3c. Note that the complete cycle occurs in one-thirtieth of a second, and that the zero line is traced out twice in each cycle.

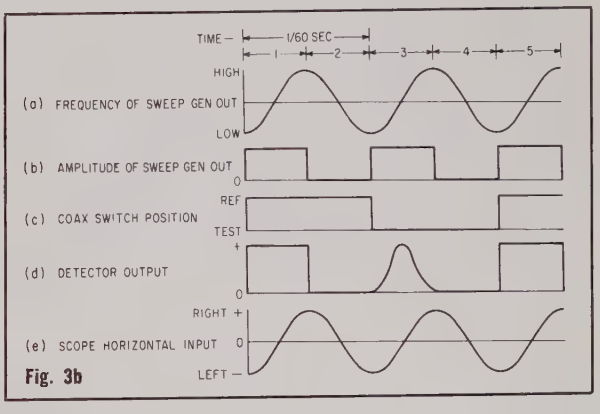


Fig. 3b

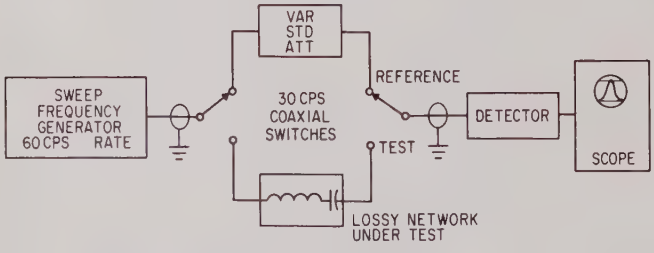


Fig. 3a—Operation of 2-Way Comparator Model FD-30

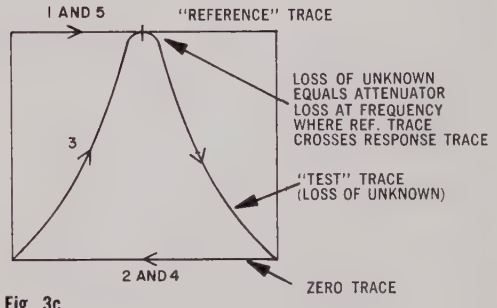

1 AND 5
"REFERENCE" TRACE
LOSS OF UNKNOWN EQUALS ATTENUATOR LOSS AT FREQUENCY WHERE REF. TRACE CROSSES RESPONSE TRACE
3
"TEST" TRACE (LOSS OF UNKNOWN)
2 AND 4
ZERO TRACE
Fig. 3c

Figure 4a illustrates the application of the three-way comparator using two attenuators to show simultaneously the maximum response and the 3 db down point of a resonant circuit on an oscilloscope. Figure 4b diagrams the sequence of operations. Note that the switches "A" close during the first quarter cycle, connecting attenuator "A" into the circuit; switches "B" close during the next quarter cycle connecting attenuator "B" into the circuit; during the third quarter cycle, switches "C" close, connecting the unknown; and all switches are open during the fourth quarter cycle, producing the zero base line. The resulting scope trace is shown in Figure 4e. The response curve is displayed with a zero base line and two reference lines. The position of the reference lines on the trace corresponds to the attenuation of two separate attenuators.

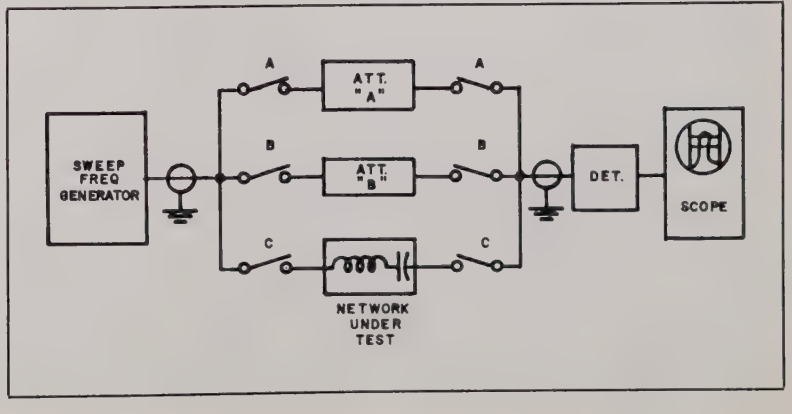


Fig. 4a
Operation of
3-Way Comparator
Model TC-3

This three-way display allows, for example, setting up a production test position with high and low limits of gain, loss, or impedance, keyed into the scope so that all calibrations are independent of generator output or scope drift.

Figure 5 shows a block diagram of the transistor driver employed to obtain this operation. With the input switch in INT position, the synchronizing input is obtained from a 60-cycle AC connection to the power supply through a 360° phase shifter. With the switch on EXT, an external synchronizing input may be used at any frequency between zero and several hundred cycles. A source capable of supplying six volts peak-to-peak into 20,000 ohms is required. Regardless of the input wave form, the switches will operate about one millisecond after each zero volt cross-over.

The internal or external synchronizing signal is shaped by a Schmitt trigger and clipper and the resulting square wave, which has the same frequency as the synchronizing source, is applied to a two-to-one counter generating a square wave at ½ that frequency. Both square wave voltages are applied to a diode AND gate, which controls the input to three driver transistors so that these are keyed in the sequence required to drive the relay coils. A function switch selects one of three switching mode connections to the driver transistors so that relay switching can be performed either: manually, or by three-way automatic switching, or by two-way automatic switching giving operation similar to the FD-30.

Three reed relays are used in each of two heads, mounted coaxially to obtain the best possible impedance match up to 1200 MC. The impedance match, when the switch is terminated in a precise 50 ohms, is held to a close tolerance as shown by the characteristic in Figure 6. The relay units were selected to give an unusually high degree of isolation when open, and low insertion loss when closed. The insertion loss, when the switch is closed, is less than 0.1 db from DC to 1200 MC. When open, the capacity is less than 0.085 pf giving an insertion loss which decreases with frequency, as shown in Figure 7.

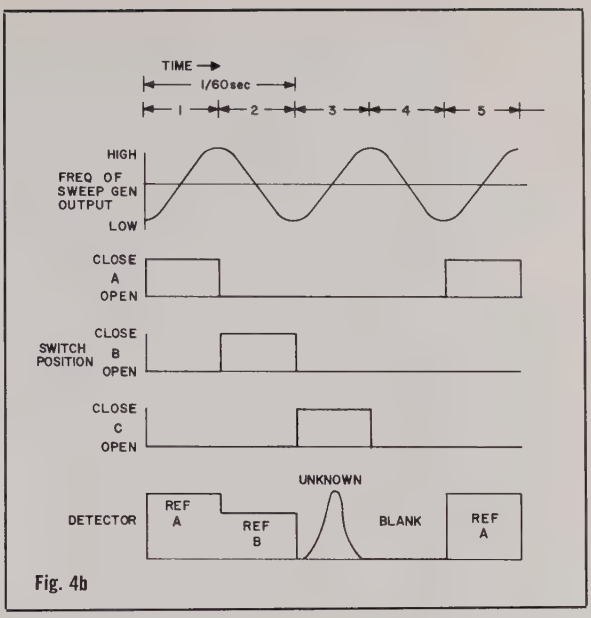


Fig. 4b

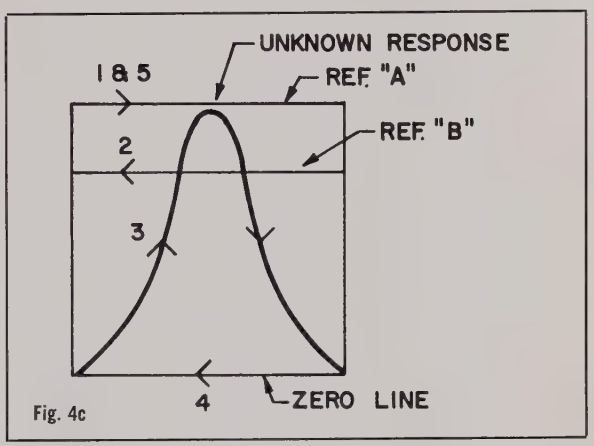


Fig. 4c

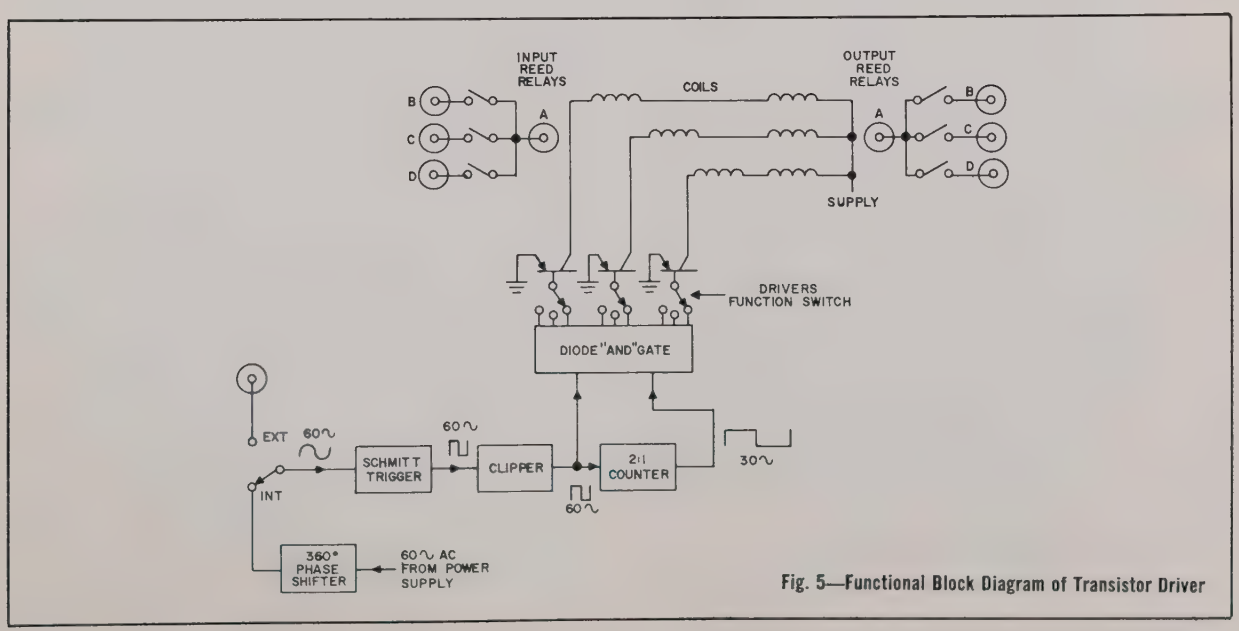


Fig. 5—Functional Block Diagram of Transistor Driver

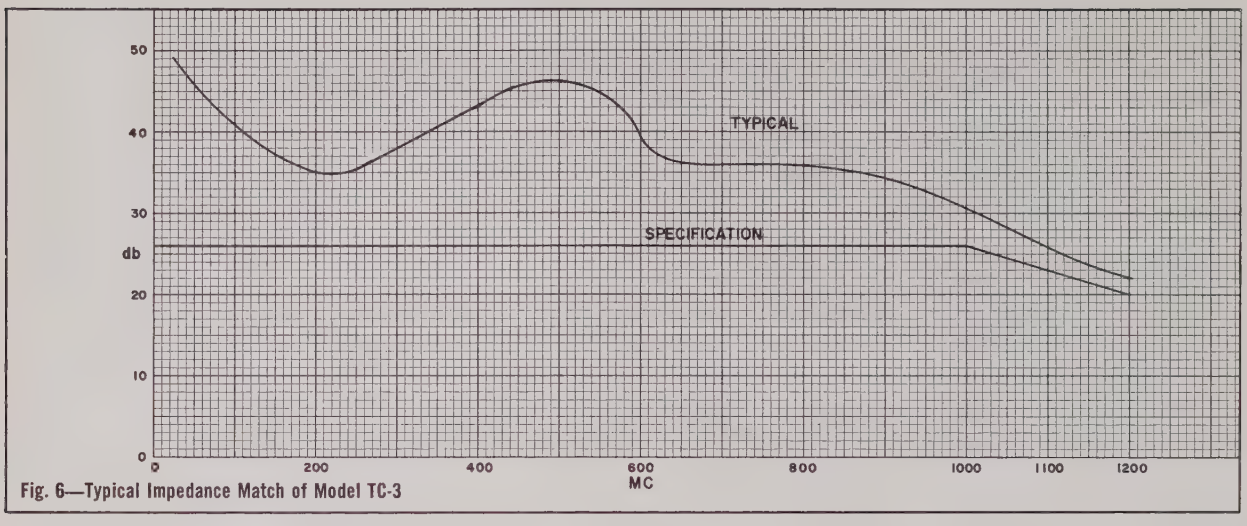


Fig. 6—Typical Impedance Match of Model TC-3

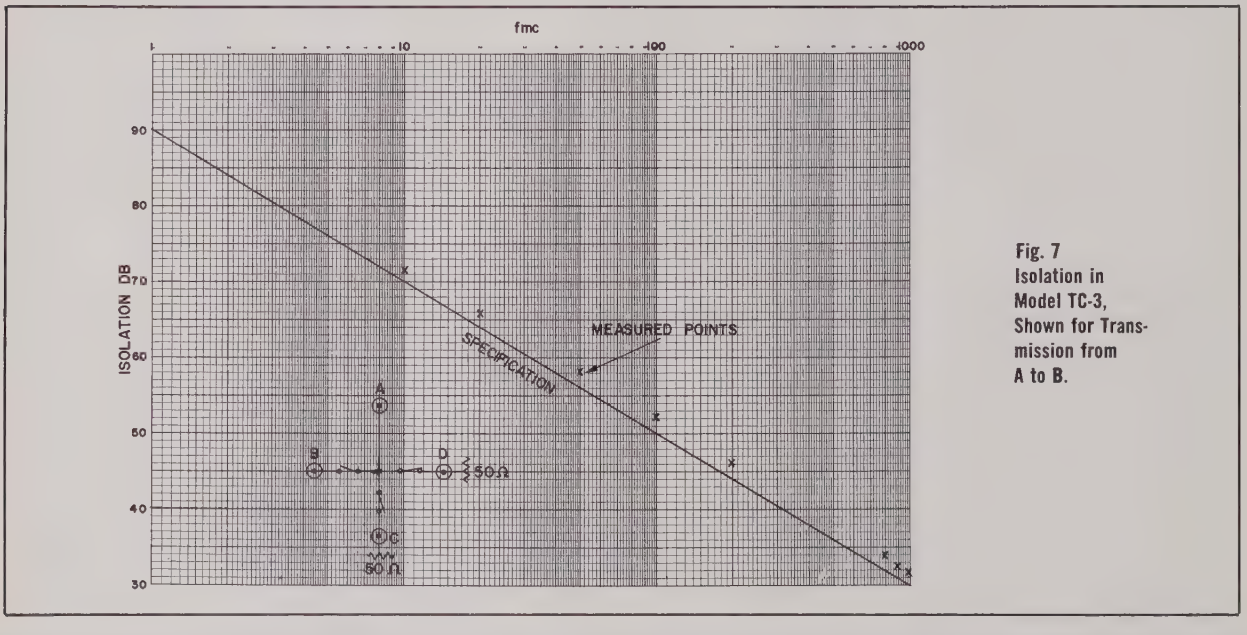


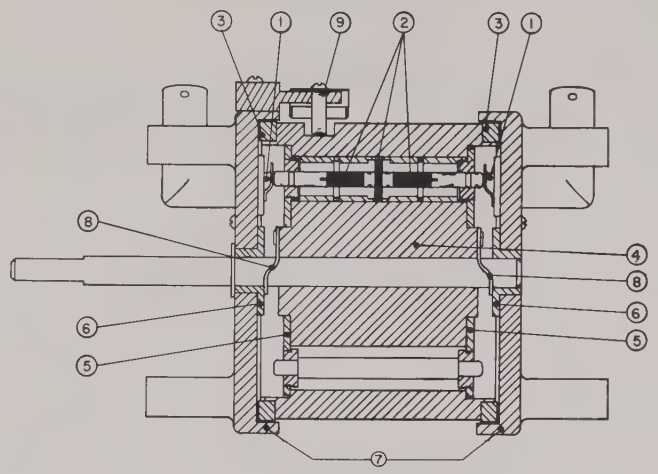
Fig. 7
Isolation in Model TC-3, Shown for Transmission from A to B.

MODEL ATV ATTENUATORS

The design selected for the new attenuators strikes a happy compromise between two extremes. Variable attenuators available today fall into two general categories. The best commercially available units are drum attenuators with an upper frequency limit of 2 to 4 GC. Several of the available types are pull-and-turn mechanisms which have optimum electrical performance at the expense of mechanical convenience. Prices are in the vicinity of $750 to $800 for a 10-position drum. All of the best units use disc and rod assemblies with either deposited carbon or film resistors.

At the other extreme there are many types of less expensive attenuators which cost less than $200. These generally use deposited or molded carbon resistors and various switching arrangements, either the progressively additive type (like our AV-50) or rotary switches. While these are excellent for low frequency applications and have good mechanical convenience, it is very difficult to maintain acceptable performance up to 1 GC with any arrangement where resistive elements are connected into the attenuator with wire leads.

Fig. 2 illustrates a rack-mounting bank of attenuators (Model ATV-109). A cross-section view of a turret is given in Figure 8. The highest quality deposited carbon rod and disc assemblies are used, mounted coaxially to take full advantage of their excellent match and attenuation capabilities. Spring contacts are employed between the attenuator element and the input and output connectors. While this construction does not provide as good a coaxial connection as might be obtained with a pull-and-turn arrangement, with careful design it has been made to give excellent performance to our top frequency objective of 1200 MC. The carefully-machined castings and well-designed detent ensure accurate and trouble-free operation. Complete RF shielding is assured by the use of RF gasketing material. The impedance match characteristics and attenuation accuracy of a typical 0-50 db drum are illustrated in Figures 9 and 10.



1. Coin silver contacts.
2. Disc and rod pad resistors for accuracy and long time-stability. Low VSWR assured with machined compensating sleeves.
3. Resilient rf gasketing for good ground contact and shielding.
4. Solid aluminum rotor, precision machined for accuracy and stability.
5. Important rf grounds carried by silver plated brass rings.
6. Brass bearing inserts for minimum wear.
7. Machined aluminum end castings to maintain alignment.
8. Coin silver inner contact grounding spring (necessary on some models only).
9. Positive spring-loaded ball bearing detent mechanism with faultless resolution.

Fig. 8—Cross-Section of Turret Attenuator

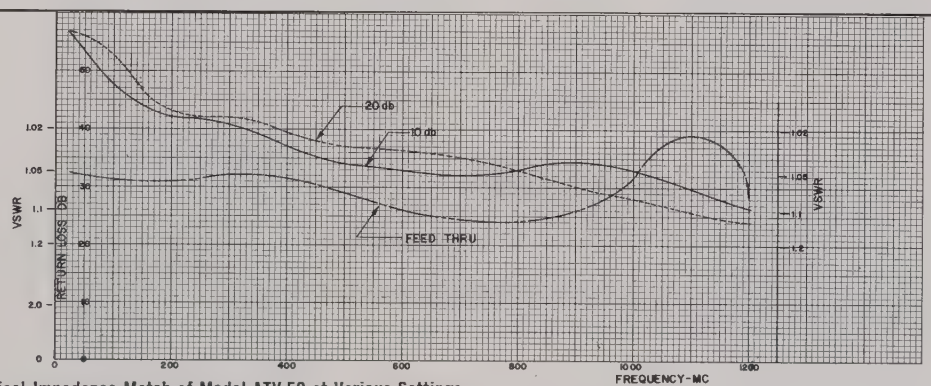


Fig. 9—Typical Impedance Match of Model ATV-50 at Various Settings

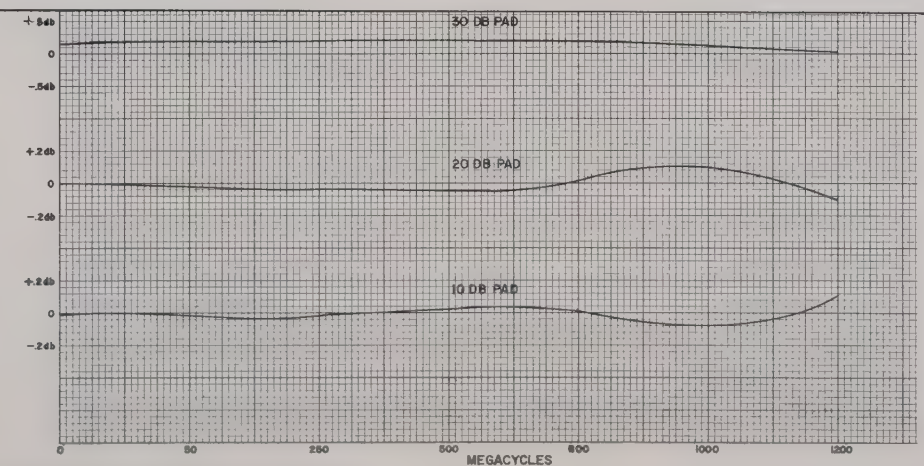


Fig. 10—Typical Attenuation Tolerance of Model ATV-50

Design of the attenuators and comparators was carried out under the direction of Henry Arbeiter. He also is responsible for electrical design of the attenuator, working with Eric Winston on mechanical design. John Austin designed the reed-relay heads on the TC-3, Frank Egenstafer is responsible for the transistor driver, and Earl Nickerson for the styling.

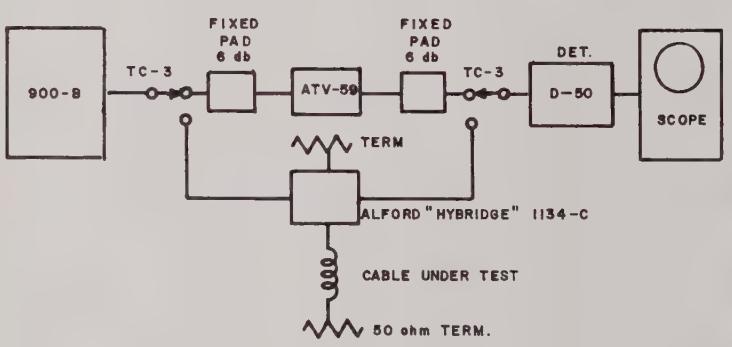
MODEL 890 WIDE-BAND SWEEPER

Model 890

Latest in Jerrold's proven group of sweep frequency generators is the new, moderately priced Model 890. This sweeper, although somewhat less sophisticated in its design than the Model 900-A, nevertheless incorporates all of that instrument's basic circuitry necessary to permit a highly economical production line test set-up.

Together with the new comparator and attenuators, the 890 will afford fast, repetitive measurements for simultaneous low and high limit comparison. Tests can be made up into the UHF range of 1100 MC, at a top center frequency setting of 1000 MC with a sweep width variable from 100 KC min. to ± 10% of center frequency.

TYPICAL APPLICATIONS IN MEASUREMENTS BY COMPARISON



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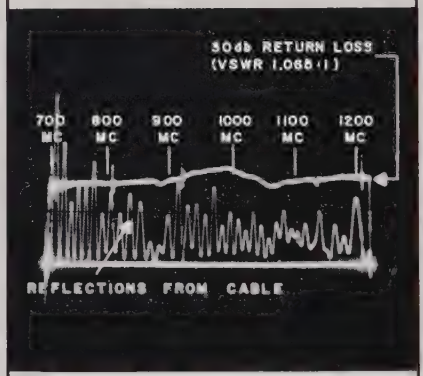
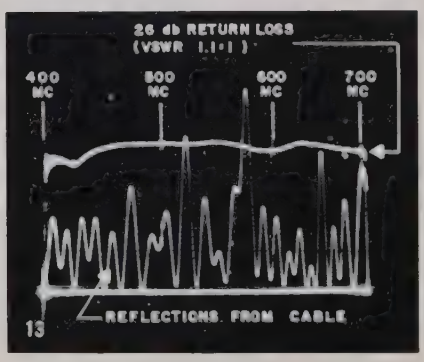


12

Application of Models TC-3 and ATV-50 in testing the impedance characteristics of coaxial cables. The test involved approximately 50 ft. of type RG-8A/U flexible coaxial cable, carefully terminated at the other end. Photo 12 illustrates the trace for measurement between 700 and 1200 MC; photo 13 illustrates the trace for measurement between 400 and 700 MC. The impedance variations on each trace are due to mechanical irregularities in the tested cable.

Note that there are decidedly less irregularities in photo 12, where the cable would meet a specification of 30 db (better than most cables).



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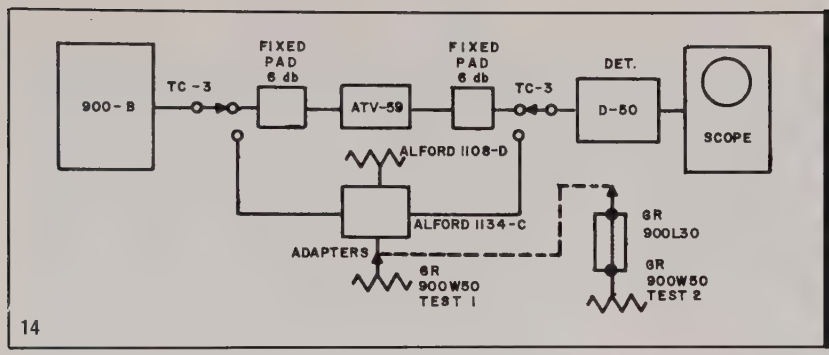
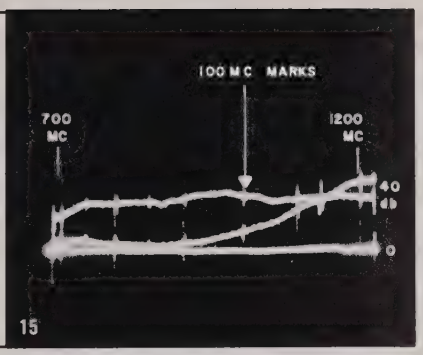




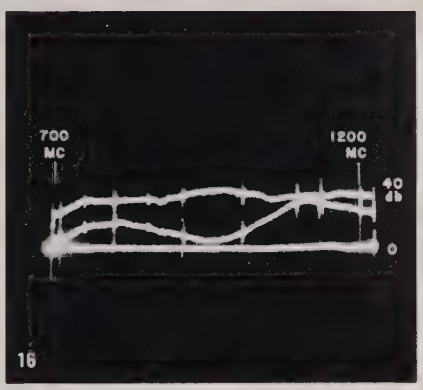
Application of Models TC-3 and ATV-50 in testing the sensitivity of Model 900-B and for checking the accuracy of the bridge test set-up.
Two tests were made:

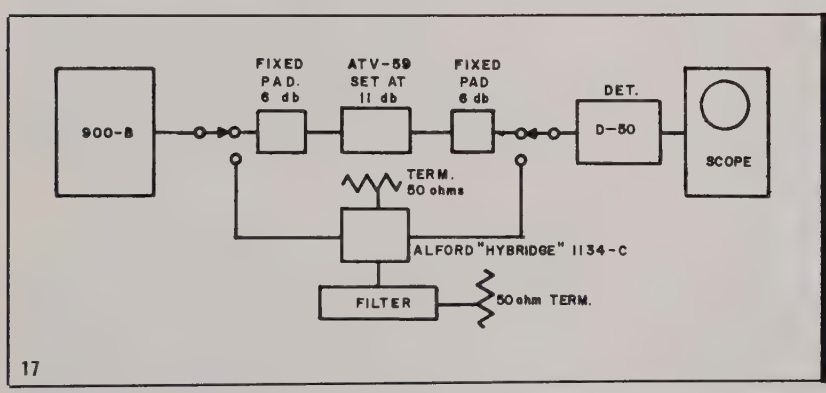
1. connecting a General Radio type 900W50 precision 50-ohm termination through two adapters, first a General Radio type 900Q874, followed by a General Radio type 874QNP, to the bridge.

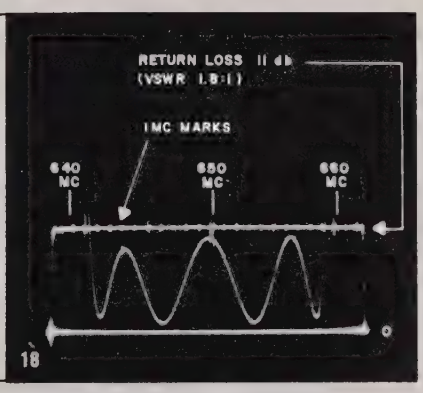
   Photo 15 shows that the bridge measured somewhat better than 40 db match (VSWR 1.02:1) up to 1100 MC.

2. connecting a 30 cm length of precise 50-ohm air dielectric line, General Radio type 900L30, between the termination and the 900Q874 adapter.

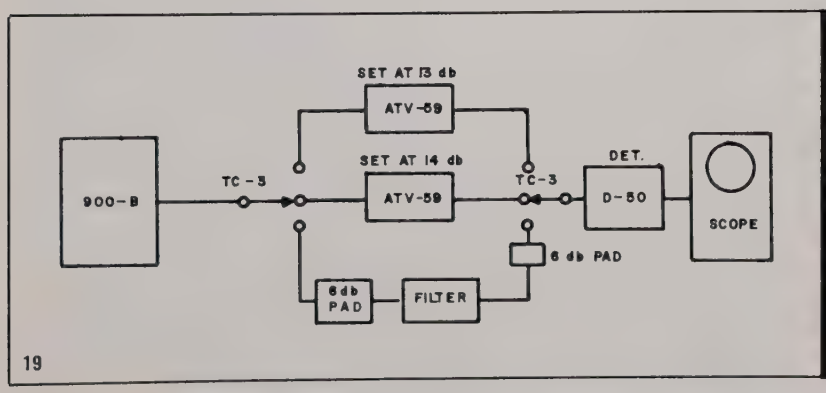
   If the characteristic impedance of the air line were exactly equal to that of the termination, the impedance would be unchanged in the second test. As seen in photo 16, there was a slight change, but the resulting impedance was still seen by the bridge as better than a 40 db match.

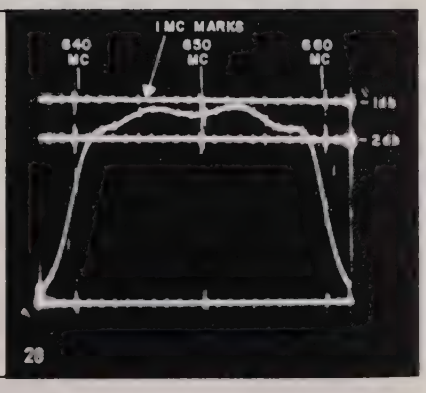




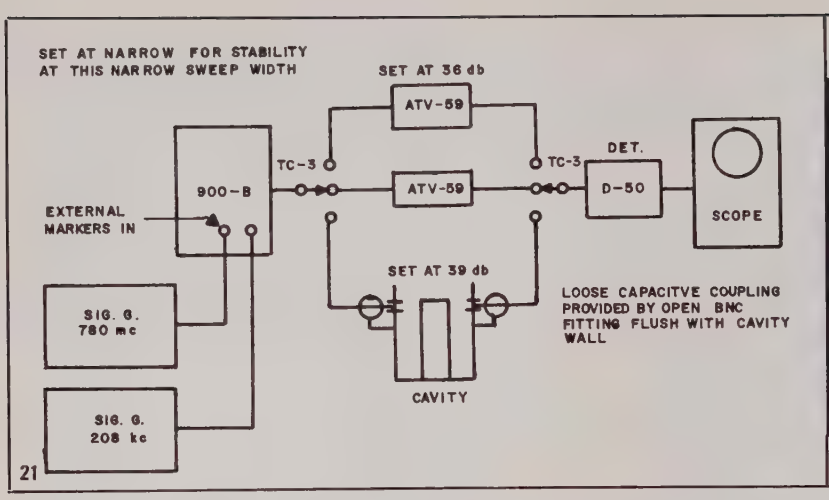


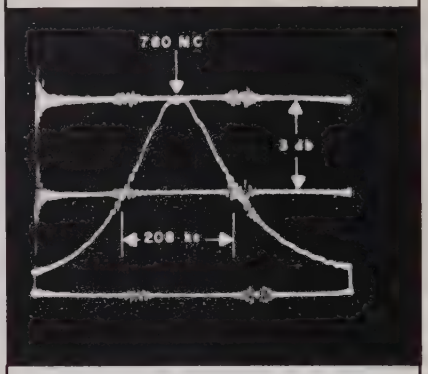
Application of Models TC-3 and ATV-50 to impedance match measurement on a four-pole band-pass filter.



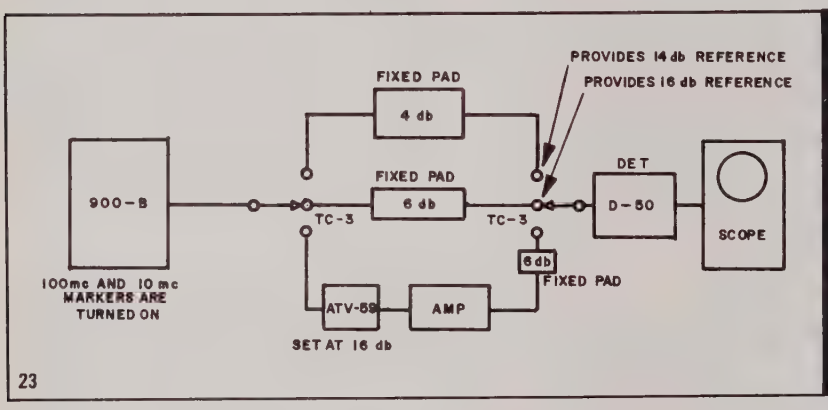


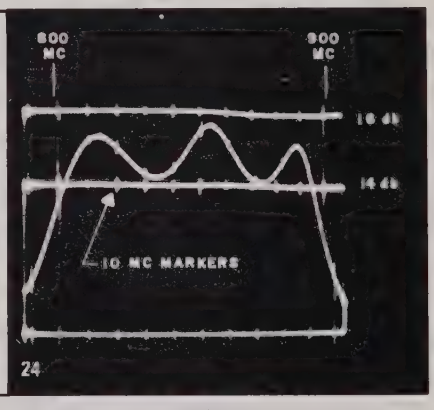
Application of Models TC-3 and ATV-50 to measurement of insertion loss of filter the match of which was shown in photo 18.



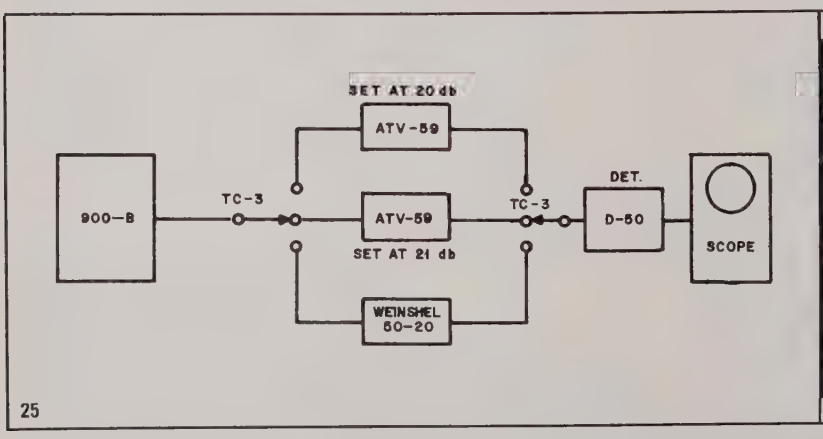


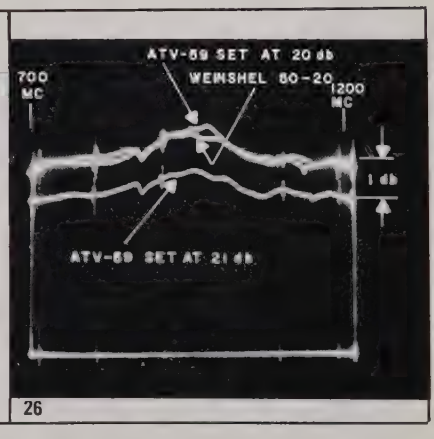
Application of Models TC-3 and ATV-50 to measurement of unloaded bandwidth and thus Q of 780 mc resonant cavity. Resulting $Q = \frac{fo}{\Delta f} = \frac{780}{0.208} = 3750$





Application of Models TC-3 and ATV-50 to measurement of gain of a transistorized UHF amplifier. Gain limits are 16 and 14 db; design bandwidth was 806 to 890 MC.





Comparison of Model ATV-50 with a Weinshel attenuator pad which had been calibrated at 20.0 db at 1000 MC. Differences between the two curves are about 0.1 db maximum, some of which is due to short cable jumpers.

NOTE — Additional copies of this paper and engineering assistance on the application of Measurements By Comparison may be obtained by contacting the Industrial Products Division, Jerrold Electronics Corporation, 15th & Lehigh, Phila., Pa. 19132. Phone: BAldwin 6-3456 — Ext. 215.

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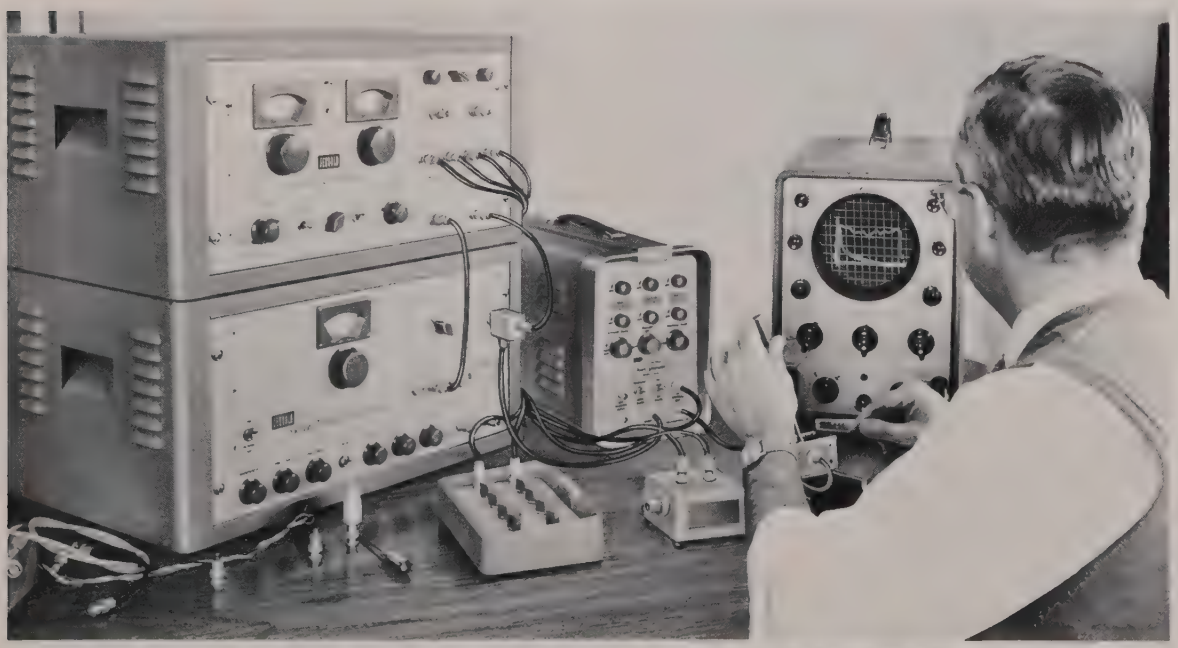
A Bridge Method of Sweep Frequency Impedance Measurement

by KEN SIMONS, Chief Engineer, Jerrold Electronics Corp.

The following is an extract of a speech given by Mr. Simons at the First Annual Eastern Engineering Seminar, May 5, 1960, Hotel Bradford, Boston, Massachusetts.

SUMMARY:

A matched bridge circuit is described providing oscilloscopic display and measurement of return loss vs. frequency. Units have been constructed allowing measurement of 50 db return loss over a 50 to 1 frequency range (4-200 MC). The technique is useful from low audio frequencies up to several hundred megacycles.



A typical test set-up utilizing Jerrold Models—900-A Sweep Frequency Generator, VC-12 Voltage Comparator, CM-6 Marker Generator, AV-75 Variable Attenuator and KSB-75 ohm Bridge; to show an optimum termination, 4 mcs to 100 mcs, with a 50 db reference.

FUNDAMENTALS:

Since high frequency measurements frequently require unavoidable lengths of transmission line, high frequency measuring techniques usually involve an application of transmission line principles. The bridge circuit to be described is no exception. Understanding its operation requires a clear picture of the concepts of reflection coefficient and return loss.

Consider an AC generator with internal impedance Ro and a voltage E as illustrated in Figure 1 (a). When the output

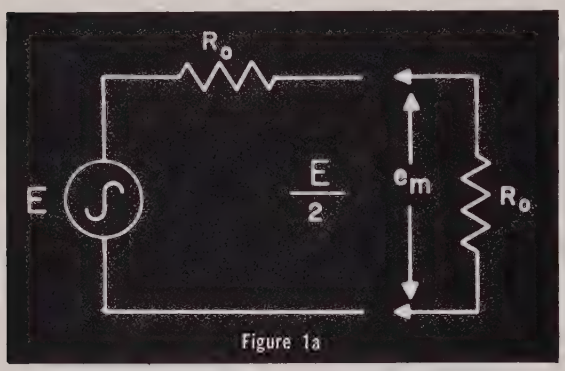


Figure 1a

of this generator is connected to a load having an impedance equal to Ro, the output voltage is $\frac{E}{2}$. In the particular case where this load is the input impedance of a section of transmission line having a characteristic impedance Ro, it is convenient to consider the input voltage as consisting of two components—a main voltage wave (e_m) which travels down the line away from the generator, and a reflected wave (e_r) which travels back from the far end towards the generator. When the transmission line section is terminated in Ro, the reflected wave is zero and the input voltage is simply e_m Figure 1 (b).

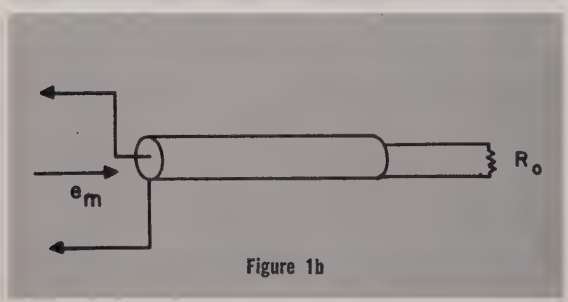


Figure 1b

This terminology can be applied even when there is no transmission line in the circuit. It may correctly be said in reference to Figure 1 (a) that the voltage across the load Ro is e_m.

In the case where the generator feeds a section of transmission line terminated in some impedance other than Ro, the input voltage can be considered to be the sum of e_m and e_r (Figure 1c). Similarly the voltage across any load

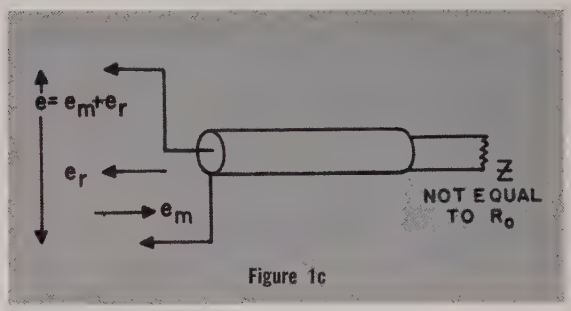


Figure 1c

connected to a generator can be considered to be the sum of a main wave and a reflected wave (Figure 1d).

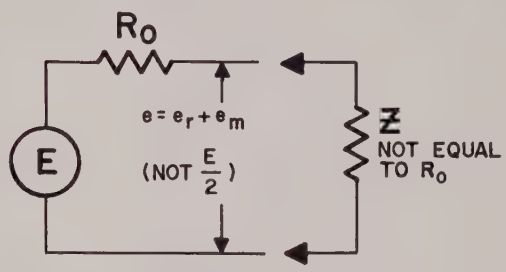
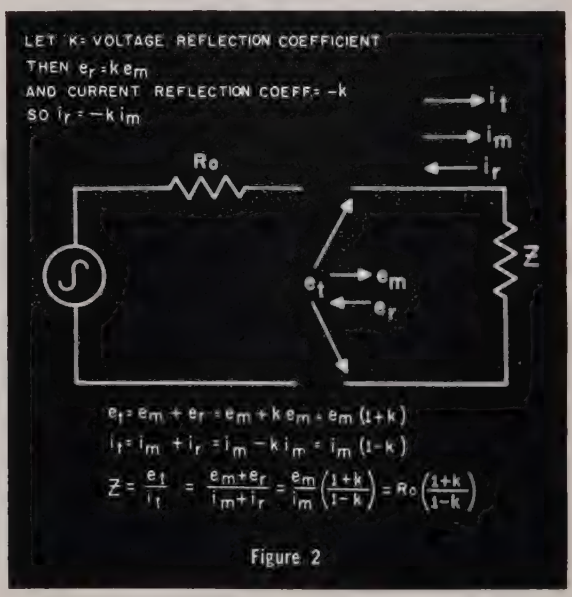


Figure 1d

A convenient way of describing the relation between the main and reflected waves is to use the reflection coefficient. Figure 2 illustrates a generator feeding a load having any impedance "Z". The voltage and current across this load


LET K= VOLTAGE REFLECTION COEFFICIENT
THEN er = k em
AND CURRENT REFLECTION COEFF= -k
SO ir = -k im
it
im
ir
Ro
et
em
er
Z
et = em + er = em + k em = em (1+k)
it = im + ir = im - k im = im (1-k)
Z = et/it = (em+er)/(im+ir) = (em/im)((1+k)/(1-k)) = Ro((1+k)/(1-k))
Figure 2

are expressed in terms of their main and reflected components. The quantity k is defined as the ratio of the reflected voltage e_r to the main voltage e_m. The current reflection coefficient is numerically equal to the voltage reflection coefficient and has the opposite sign, so that the relationships indicated in Figure 2 hold true. A significant point is that the impedance of the load can be fully described by the internal impedance of the generator and the voltage reflection coefficient. The relation is:

$$\bar{Z} = Ro \frac{1 + k}{1 - k}$$

Note that k is a complex number involving the relation between not only the magnitudes of the main wave and reflected wave, but also their phase angles.

A further convenience is achieved by expressing the reflection coefficient logarithmically. The "Return Loss" is defined as 20 $\log_{10}\frac{1}{k}$. Thus, it is the ratio of e_r to e_m expressed in decibels. The interrelation between Return Loss, Reflection Coefficient and VSWR is indicated on the Nomograph of Figure 3.

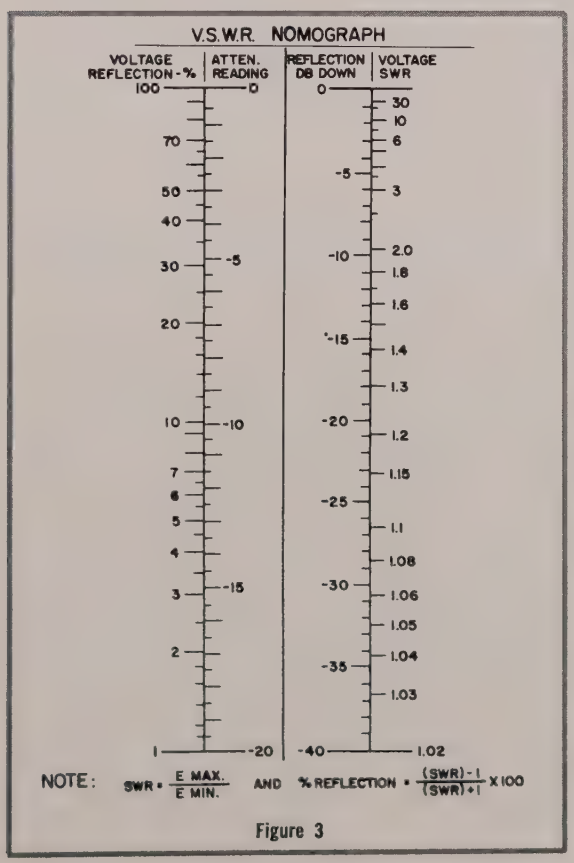


Figure 3

THE BRIDGE PRINCIPLE:

A convenient way of measuring an unknown impedance would be to separate the reflected wave from the main wave and to measure its relative magnitude and phase angle. This is commonly done in high-frequency and microwave testing by the use of a directional coupler. Another approach is the use of a bridge.

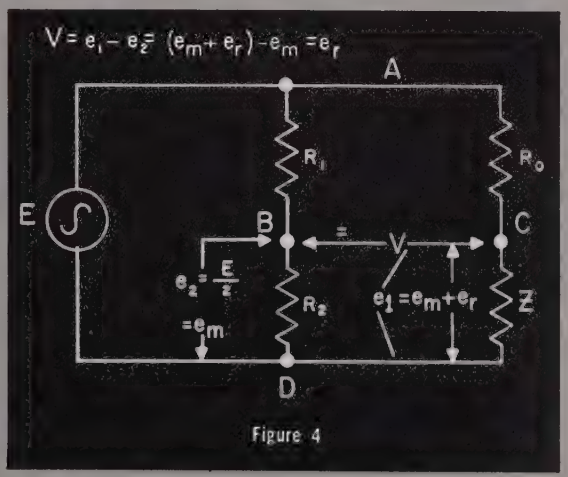


Figure 4

Figure 4 illustrates how a bridge can provide a voltage equal to the reflected wave. A generator having zero internal impedance feeds a load $\bar{Z}$ through a resistor Ro. The voltage e_r across $\bar{Z}$ is equal by definition to e_m plus e_r. If a second divider consisting of two equal resistances R_1 and R_2 is connected across the voltage source, the voltage e_2 across the lower resistor will be equal to $\frac{E}{2}$ which is the same as e_m. If the voltage between the center points of the two dividers is measured, it is found to be the difference between e_m plus e_r and e_m, which is e_r. Thus, the output voltage "V" of this network is identical to the reflected voltage component from the impedance $\bar{Z}$.

THE TERMINATED BRIDGE:

Unfortunately, this simple circuit involves the use of a voltage source having zero internal impedance and a voltage measuring device having infinite impedance which measures the difference of voltage between two points, neither of them grounded. As a practical matter, these conditions are difficult to approach.

Fortunately, an alternative configuration is available. The terminated bridge illustrated in Figure 5 has several characteristics which make it especially suitable for this application. When all six resistances are equal, the impedance seen looking into the network at the terminals left after disconnecting any one of the resistances is always equal to Ro. Thus, for example, in Figure 5 the impedance seen between A and D with #1 resistor removed is equal to Ro. When the resistors are equal to the characteristic impedance of a particular coaxial cable, the bridge has matched input and output impedances.

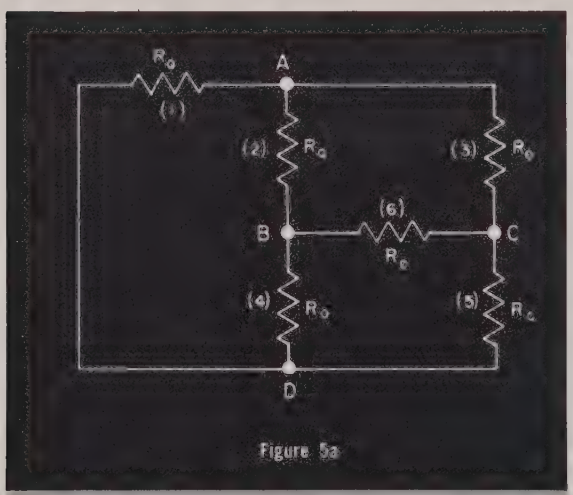


Figure 5a

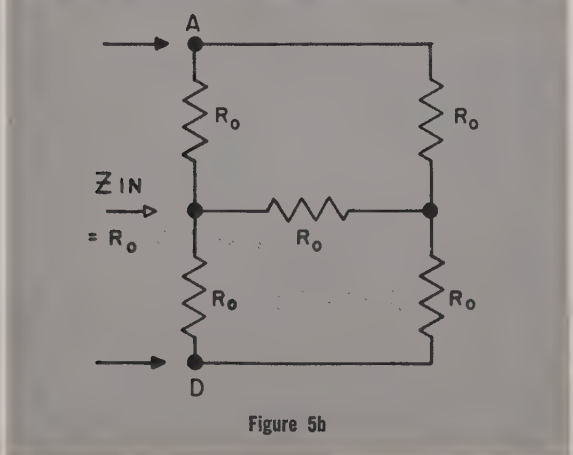
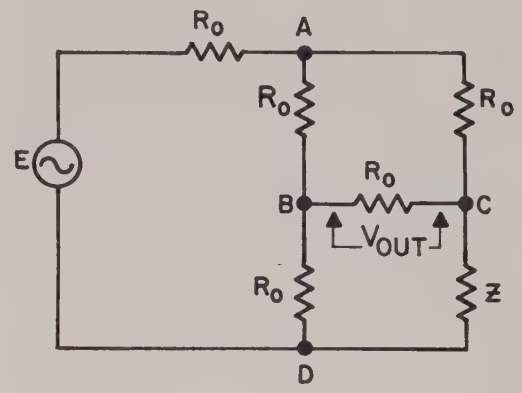


Figure 5b

The terminated bridge has the further advantage that it provides an output voltage precisely equal in magnitude and phase to a constant times the reflection coefficient of the unknown. This is illustrated in Figure 6 which states



TRANSMISSION LOSS IS $20 \log_{10} \left(\frac{E}{2 V_{OUT}} \right)$

$= 20 \log_{10} 4 \times \frac{Z+R_o}{Z-R_o}$ = RETURN LOSS OF Z+12db

Figure 6

that the transmission loss from the input terminals of the bridge, to Vout is equal to the return loss of Z (referred to Ro) plus 12 db. This relation is fully derived in Appendix I. It may be understood better by referring to Figures 7 and 8. Figure 7 shows that the input voltage to a matched load connected between C and D (e_m) is equal to the bridge input Vin reduced by 6 db.

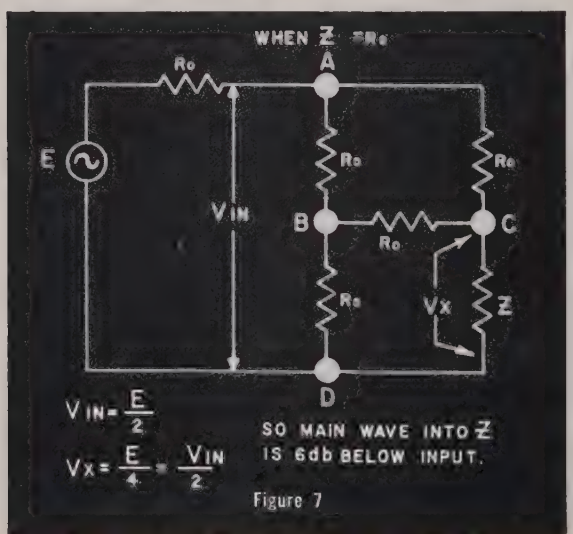


Figure 7

In Figure 8 the bridge is redrawn to show the voltage division experienced by the return wave from Z. It comes back into terminals C and D and is attenuated 6 db before coming out of terminals B and C.

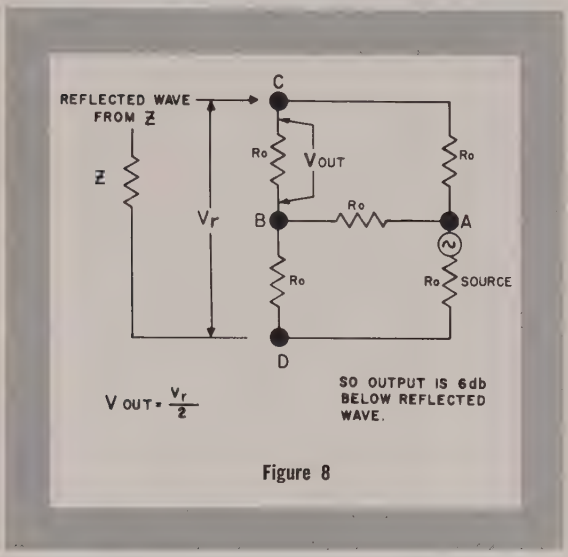


Figure 8

As compared with the simple bridge circuit illustrated in Figure 4, the matched bridge has the advantage that the input and output impedances match connecting coaxial cables so that wide band frequency performance can be obtained. The problem of providing a differential voltage measurement between two ungrounded terminals is still present. To build a matched bridge practically, it is necessary to provide a transformer having balanced input terminals as illustrated in Figure 9. It has been found

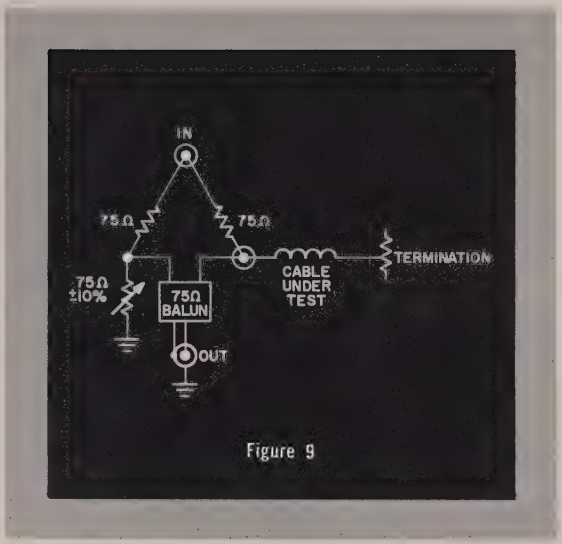


Figure 9

possible to build such a transformer with a very wide range of frequency response. The resulting bridge is conveniently connected to provide a calibrated sweep display as illustrated in Figure 10. A high-speed coaxial switch (Jerrold Model FD-30) is connected so that in the "up" position it connects the output of the sweep through a 12 db pad and a standard variable attenuator to the input of a wide band amplifier. The amplifier is followed by a detector and scope and displays a curve representing loss vs. frequency. In the "down" position the switches insert the bridge in place of the attenuators. Since the loss of the bridge is equal to the return loss of the unknown plus 12 db, the scope will show a plot of return loss vs. frequency with a reference line corresponding to the setting of the standard variable attenuator.

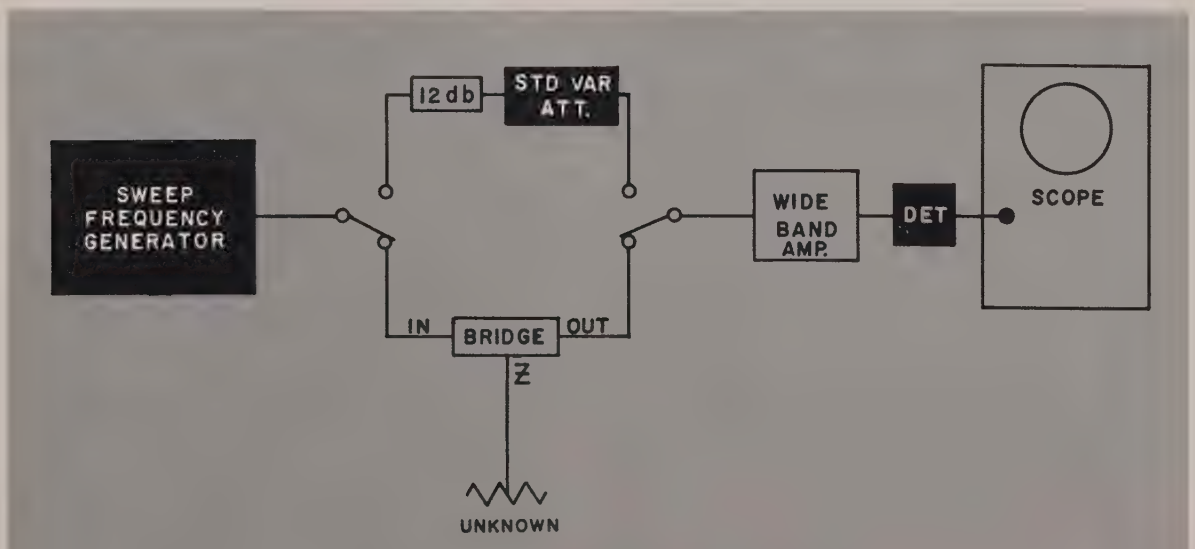


Figure 10—BRIDGE SWEEP FREQUENCY TEST SET-UP

EXAMPLES OF USE

The performance of a particular bridge is illustrated in Figures 11 to 16 inclusive. This bridge was designed for a characteristic impedance of 75 ohms and the test circuit covered a frequency range from 4 to 100 MC. Figure 11 illustrates the relation between the reference line and the bridge response with the unknown terminal of the bridge open-circuited. The bridge indicates 0 db return loss within about ½ db from 4 to 100 MC.

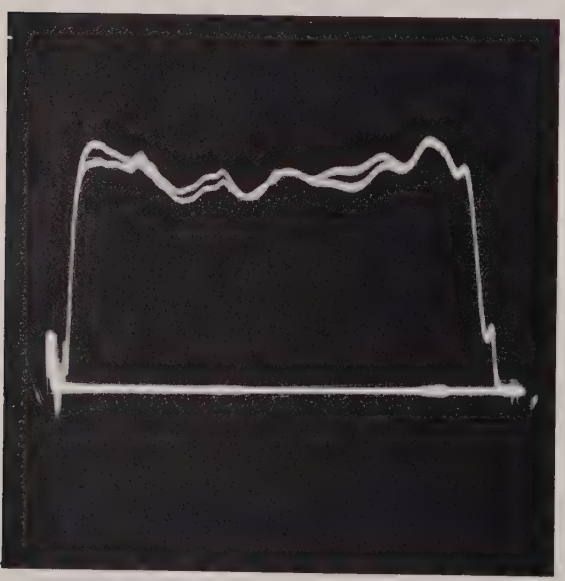


Figure 11—BRIDGE RESPONSE
4-100 mc, Open Circuit

Figure 12 shows the same situation with the unknown terminal short-circuited, again indicating 0 db return loss with approximately ½ db error.

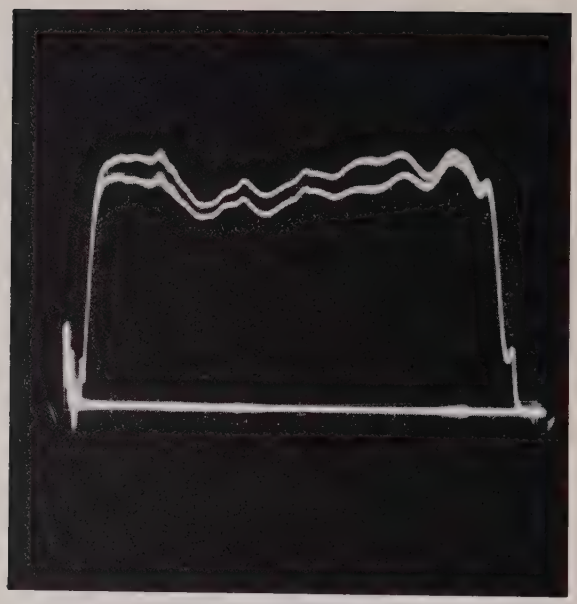


Figure 12—BRIDGE RESPONSE
4-100 mc, Short Circuit

To obtain Figure 13, the X terminal of the bridge was terminated as accurately as possible. In this figure the reference line represents a return loss of 50 db and it is seen that the loss through the bridge indicates a return loss substantially better than 50 db across this entire frequency range. A 50 db return loss corresponds to a VSWR of 1.06 so that it is apparent that this technique is capable of precision comparable with the best that can be obtained with other high frequency measuring techniques.

Figure 13—BRIDGE RESPONSE
4-100 mc, Optimum Termination, 50 db Reference

Although this method is extremely **precise**, i.e., it can compare an unknown with a standard and show deviations of considerably less than 1%, its **accuracy** is entirely dependent on the accuracy of the standard impedance against which the bridge is tested. Where suitable standards are available, its accuracy can be nearly as good as its precision.

Figure 14 illustrates the agreement between the reference line and the bridge loss when the bridge was first adjusted for balance with a 75 ohm resistor. A resistor was then substituted whose DC resistance was accurately adjusted to 70 ohms. A 70 ohm resistor in a 75 ohm system gives a VSWR of 1.07 or a return loss of 29.2 db. The reference line on this trace was 30 db.

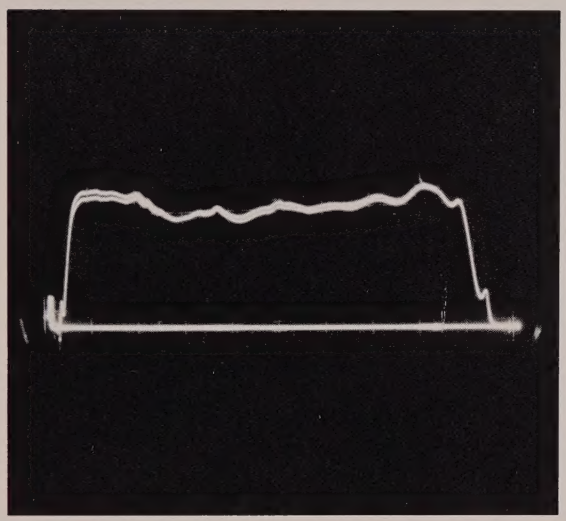


Figure 14—BRIDGE RESPONSE
4-100 mc, 70 ohm Termination, 30 db Reference

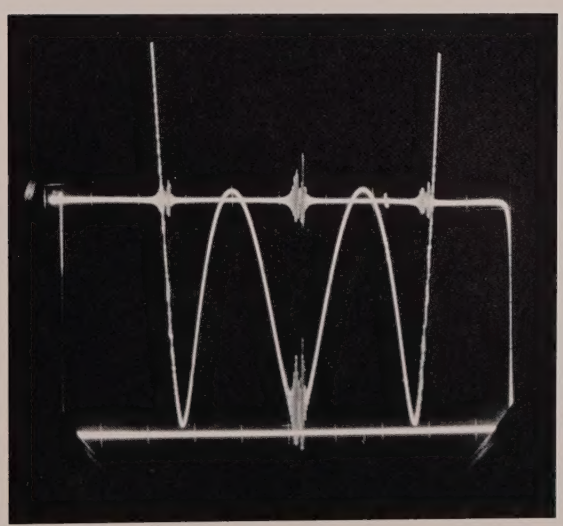


Figure 15 —BRIDGE RESPONSE
Markers 100 mc ±1.5 mc, 10 db Reference

The delay line method of sweep-frequency impedance measurement (as described in Technical Newsletter #2) provides a convenient method of measuring high frequency impedances with a minimum of equipment. Practical characteristics of delay lines limit the usefulness of this method to relatively wide frequency bands. The bridge technique has no such limitation. It is equally useful for extremely narrow-band measurements or extremely wide-band measurements.

Figure 15 shows the return loss measurement of a triple-tuned filter having a bandwidth of 1.5 MC and a maximum return loss in the pass band of approximately 10 db. Notice the simplicity of this presentation and the ease with which an operator could adjust such a filter to meet given frequency and return loss specifications.

Figure 16 illustrates an extremely wide band measurement. This shows the return loss of a piece of high-grade coaxial cable over the frequency range 4 to 100 MC with a 40 db reference. The bridge provides a way of testing this complicated function with a high degree of speed and accuracy.

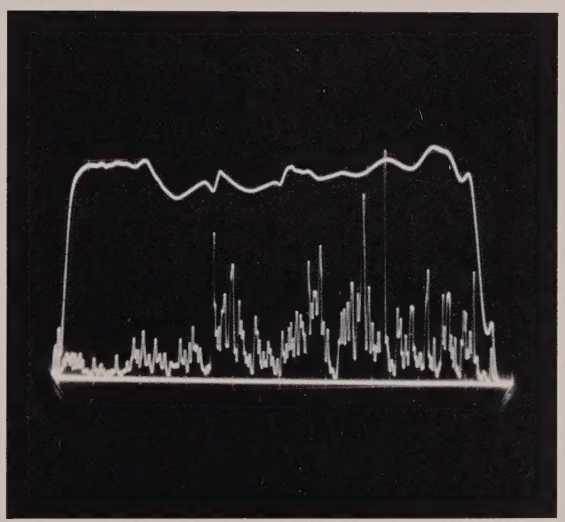
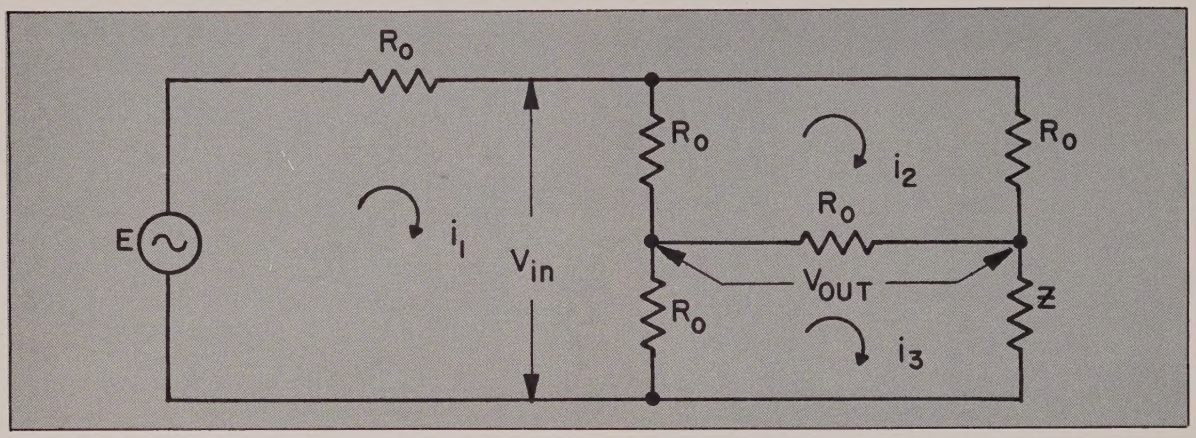


Figure 16—BRIDGE RESPONSE
4-100 mc, Input of 1000′ Piece High Grade Coax., 40 db Reference

The sweep frequency technique has for many years provided a convenient way of observing the frequency variation of gain or loss. More recently it has become possible to measure these quantities simultaneously with the sweep presentation. (See Technical Newsletter #1.) The wide-band return-loss bridge now provides the same degree of convenience in viewing and measuring the frequency variation of return loss and opens a new area of speed and convenience in Laboratory and Production testing of high frequency networks.

APPENDIX



① ..... $E = 3R_0i_1 - R_0i_2 - R_0i_3$

② ..... $0 = -R_0i_1 + 3R_0i_2 - R_0i_3$

③ ..... $0 = -R_0i_1 - R_0i_2 + (Z + 2R_0)i_3$

④ ② − ③ ..... $0 = 4R_0i_2 - (Z + 3R_0)i_3$

⑤ ① + (3 X ②) ..... $E = 8R_0i_2 - 4R_0i_3$

⑥ Solving ④ for i_2 ..... $i_2 = \dfrac{Z + 3R_0}{4R_0}\, i_3$

⑦ Substituting ⑥ in ⑤ ..... $E = 8R_0\left(\dfrac{Z + R_0}{4R_0}\right)i_3 - 4R_0i_3 = 2(Z + R_0)i_3$

hence $i_3 = \dfrac{E}{2(Z + R_0)}$

⑧ Substituting ⑦ in ⑥ ..... $i_2 = \left(\dfrac{Z + 3R_0}{4R_0}\right)\left(\dfrac{E}{2(Z + R_0)}\right) = \left(\dfrac{E}{8R_0}\right)\left(\dfrac{Z + 3R_0}{Z + R_0}\right)$

⑨ ..... $V_{OUT} = R_0(i_2 - i_3) = R_0\left[\left(\dfrac{E}{8R_0}\right)\left(\dfrac{Z + 3R_0}{Z + R_0}\right) - \dfrac{E}{2(Z + R_0)}\right]$;

hence $V_{OUT} = \dfrac{E}{8}\left(\dfrac{Z + 3R_0 - 4R_0}{Z + R_0}\right)$

and $\boxed{V_{OUT} = \dfrac{E}{8}\left(\dfrac{Z - R_0}{Z + R_0}\right)}$

Transmission Loss $= 20 \log_{10}\left(\dfrac{E}{2V_{OUT}}\right) = 20 \log_{10}\left[\dfrac{E8\,(Z + R_0)}{2E\,(Z - R_0)}\right] =$

$= 20 \log_{10} 4\left(\dfrac{Z + R_0}{Z - R_0}\right) =$ Return Loss of Z + 12 db

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NOTE— Additional copies of this paper and engineering assistance on the application of Measurements By Comparison may be obtanied by contacting the Industrial Products Division, Jerrold Electronics Corporation, 15th & Lehigh, Phila., Pa. 19132. Phone: BAldwin 6-3456 — Ext. 215.

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